BALL BEARING HEAT ANALYSIS PROGRAM

(BABHAP)

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FOREWORD

The initial effort under this study contract entitled "Lubrication Effect on Bearing Thermal Performances" was performed by Dr. Howard Yen. Without his assistance, and that of Mr. Jim Chiou, this document could not have been produced.

Although the program described herein was in its current stage of development in June 1977, funds were not available to complete the documentation and completely check out the program. Subsequently, a superior program was released by SKF Industries, Inc., for analyzing bearing systems. Therefore, this contractual study was concluded under continuation funding by using the SKF program entitled "SHABERTH" to determine its applicability to cryogenically lubricated bearing systems.

INTRODUCTION

The "Ball Bearing Heat Analysis Program" (BABHAP) is an attempt to assemble a series of equations, some of which are non-linear algebraic systems, in a logical order, which when solved, provide a complex analysis of load distribution among the balls, ball velocities, heat generation resulting from friction, applied load, and ball spinning, minimum lubricant film thickness, and many additional characteristics of ball bearing systems. These equations come primarily from Reference 1, but the film thickness originated from References 2 and 3. Although high speed digital computers have been utilized to simulate certain phenomena in high speed ball bearings, it is deemed that BABHAP is the first attempt to solve for all critical performance parameters for high speed ball bearings within a single computer program. Therefore, on verification by test data, BABHAP will provide a unique tool for high speed ball bearing design applications.

Although initial design requirements for BABHAP were dictated by the core limitations of the PDP 11/45 computer (approximately 8K of real words with limited number of instructions, the program dimensions can easily be expanded for large core computers such as the UNIVAC 1108. The PDP version of BABHAP is also operational on the UNIVAC system with the exception that the PDP uses 029 punch and the UNIVAC uses 026. A conversion program was written to allow transfer between machines.

A complete listing of BABHAP is contained in the Appendix.

TECHNICAL DISCUSSION

BABHAP is designed to simulate the performance of a series of single row, angular contact ball bearings mounted on a shaft, with either the inner or outer raceway rotating. The analyst using BABHAP should be familiar with the properties of bearings and lubricants, and have some knowledge of solution techniques for non-linear algebraic equations. A copy of Reference 1 would also enhance the user's understanding of this document and of BABHAP. A limited introduction to the solution of non-linear algebraic equations is contained in the PROGRAM BRIEF section of this document, describing the function of the NLINEQ routine.

The analyst must supply several input parameters which describe the physical properties of the bearing system and the lubricant. Additional inputs are the loads which the bearing system carries. The total list of inputs is described in the INPUT PARAMETERS section.

Figure 1 contains the major sections of BABHAP. As with any set of non-linear algebraic equations, an initial guess is necessary for their solution. Equations (1), (2), and (3) provide the initial guess for the relative axial displacement, the relative radial displacement, and the misalignment angle respectively.

$$\delta_a = 1.58 \times 10^{-5} \left(\frac{F_{ah}}{Z_h \sin\alpha} \right)^{2/3} \left(D^{1/3} \sin\alpha \right)^{-1} \tag{1}$$

$$\delta_r = 8.71 \times 10^{-7} \left[\frac{2.5\left(P_h^{k-1} + P_h^{k}\right)}{Z_h \cos\alpha} \right]^{0.9} \left(\ell_h^{0.8} \cos\alpha \right)^{-1} \tag{2}$$

$$\theta = \frac{2\delta_a}{d_o} \tag{3}$$

Equations (4), (5), (6), and (7) are intermediate calculations.

$$f_i = \frac{d_i}{2D} \; ; \qquad f_o = \frac{d_o}{2D} \tag{4}$$

$$\overline{BD} = (f_o + f_i - 1) D \tag{5}$$

$$dm = 1/2 \; (d_o + d_i) \tag{6}$$

$$R_i = 1/2 \; dm + (f_i - 0.5) \; D \cos \alpha° \tag{7}$$

Figure 2 contains a typical ball bearing configuration describing the value of ball position angle ψ, which is determined within the program based on the number of balls in the bearing. Figure 3 describes ball center positions which are related to equations (8) and (9).

$$S_{xj} = \overline{BD} \sin \alpha + \delta_a + \theta \, R_i \cos \psi_j \tag{8}$$

$$S_{zj} = \overline{BD} \cos \alpha + \delta_r \cos \psi_j \tag{9}$$

With the currently determined information, equations (10) through (17), which form a non-linear algebraic system, are now solved by the Newton-Raphson or Method of Steepest Descent technique, for V_j, W_j, δ_{oj}, δ_{ij}, α_{ij}, α_{oj}, F_{cj}, Mg_j.

$$(S_{xj} - W_j)^2 + (S_{zj} - V_j)^2 - [(f_i - 0.5) D + \delta_{ij}]^2 = 0 \tag{10}$$

$$W_j^2 + V_j^2 - [(f_o - 0.5) \; D + \delta_{oj}]^2 = 0 \tag{11}$$

$$\frac{\dfrac{2\lambda_j M_{gi} V_j}{D} - K_{oj} \delta_{oj}^{1.5} W_j}{(f_o - 0.5) D + \delta_{oj}} + \frac{K_{ij} \delta_{ij}^{1.5} (S_{xj} - W_j) - \dfrac{2(1-\lambda_j) M_{gj}}{D} (S_{zj} - V_j)}{(f_i - 0.5) \; D + \delta_{ij}} = 0 \tag{12}$$

$$\frac{K_{oj} \delta_{oj}^{1.5} \; V_j + \dfrac{2\lambda_j M_{gj} W_j}{D}}{(f_o - 0.5) D + \delta_{oj}} - \frac{K_{ij} \delta_{ij}^{1.5} (S_{zj} - V_j) + \dfrac{2(1-\lambda_j) M_{gj}}{D} (S_{xj} - W_j)}{(f_i - 0.5) D + \delta_{ij}} - F_{cj} = 0 \tag{13}$$

$$\cos \alpha_{ij} = \frac{S_{zj} - V_j}{(f_i - 0.5)D + \delta_{ij}} \tag{14}$$

$$\cos \alpha_{oj} = \frac{V_j}{(f_o - 0.5)D + \delta_{oj}} \tag{15}$$

$$F_{cj} = 0.001295m\ dm\ W^2 \left(\frac{W_m}{W}\right)_j^2 \tag{16}$$

$$M_{gj} = J\left(\frac{W_r}{W}\right)_j \left(\frac{W_m}{W}\right)_j W^2 \sin \beta_j \tag{17}$$

Where λ_j is 1 for outer race control and 0 for inner race control, β_j is determined from equation (18) or (19), $(W_R/_W)_j$ from equation (20) and $(W_m/_W)_j$ is determined from Table 1.

$$\tan \beta_j = \frac{\sin \alpha_{oj}}{\cos \alpha_{oj} + \gamma'} \qquad \text{for outer raceway control} \tag{18}$$

$$\tan \beta_j = \frac{\sin \alpha_{ij}}{\cos \alpha_{ij} - \gamma'} \qquad \text{for inner raceway control} \tag{19}$$

$$\left(\frac{W_R}{W}\right)_j = \frac{\pm 1}{\left(\frac{\cos \alpha_{oj} + \tan \beta_j \sin \alpha_{oj}}{1 + \gamma' \cos \alpha_{oj}} + \frac{\cos \alpha_{ij} + \tan \beta_j \sin \alpha_{ij}}{1 - \gamma' \cos \alpha_{ij}}\right) \gamma' \cos \beta_j} \tag{20}$$

\+ for outer race control
\- for inner race control

Where γ' is defined by equation (21).

$$\gamma' = D/_{dm} \tag{21}$$

	Outer Raceway Control	Inner Raceway Control
Inner raceway rotating	$\dfrac{1 - \gamma' \cos \alpha_{ij}}{1 + \cos(\alpha_{ij} - \alpha_{oj})}$	$\dfrac{\cos(\alpha_{ij} - \alpha_{oj}) - \gamma' \cos \alpha_{oj}}{1 + \cos(\alpha_{ij} - \alpha_{oj})}$
Outer raceway rotating	$\dfrac{\cos(\alpha_{ij} - \alpha_{oj}) + \gamma' \cos \alpha_{ij}}{1 + \cos(\alpha_{ij} - \alpha_{oj})}$	$\dfrac{1 + \gamma' \cos \alpha_{oj}}{1 + \cos(\alpha_{ij} - \alpha_{oj})}$

Table 1. $(W_m/_W)_j$ versus Raceway Control and Rotation

Empirical data has shown that the balls will roll on one raceway and roll and spin on the other. The raceway on which pure rolling only occurs is called the controlled raceway. Equations (22) and (23) supply the load deflection factors.

$$K_{oj} = \frac{1.8856\,(\Sigma\rho)_{oj}^{-1/2}\,(\delta_{oj}^{*})^{-3/2}}{\left[\dfrac{(1-\gamma_1^2)}{E_I} + \dfrac{(1-\gamma_2^2)}{E_{II}}\right]} \tag{22}$$

$$K_{ij} = \frac{1.8856\,(\Sigma\rho)_{ij}^{-1/2}\,(\delta_{ij}^{*})^{-3/2}}{\left[\dfrac{(1-\gamma_1^2)}{E_I} + \dfrac{(1-\gamma_2^2)}{E_{II}}\right]} \tag{23}$$

where equations (24), (25), (26), and (27) are intermediate calculations.

$$(\Sigma\rho)_{oj} = \frac{1}{D}\left(4 - \frac{1}{f_o} + \frac{2\gamma_{oj}}{1-\gamma_{oj}}\right) \tag{24}$$

$$(\Sigma\rho)_{ij} = \frac{1}{D}\left(4 - \frac{1}{f_i} + \frac{2\gamma_{ij}}{1-\gamma_{ij}}\right) \tag{25}$$

$$\gamma_{ij} = \frac{D\cos\alpha_{ij}}{dm} \tag{26}$$

$$\gamma_{oj} = \frac{D\cos\alpha_{oj}}{dm} \tag{27}$$

Equations (28) and (29) must be solved to determine the auxiliary parameters a*, b*, and δ* from Table 2.

$$F(\rho)_{oj} = \frac{\dfrac{1}{f_o} + \dfrac{2\gamma_{oj}}{1-\gamma_{oj}}}{4 - \dfrac{1}{f_o} + \dfrac{2\gamma_{oj}}{1-\gamma_{oj}}} \tag{28}$$

$$F(\rho)_{ij} = \frac{\dfrac{1}{f_i} + \dfrac{2\gamma_{ij}}{1-\gamma_{ij}}}{4 - \dfrac{1}{f_i} + \dfrac{2\gamma_{ij}}{1-\gamma_{ij}}} \tag{29}$$

$F(\rho)$	a*	b*	δ*
0	1	1	1
0.1075	1.0760	0.9318	0.9974
0.3204	1.2623	0.8114	0.9761
0.4795	1.4556	0.7278	0.9429
0.5916	1.6440	0.6687	0.9077
0.6716	1.8258	0.6245	0.8733
0.7332	2.011	0.5881	0.8394
0.7948	2.265	0.5480	0.7961
0.83495	2.494	0.5186	0.7602
0.87366	2.800	0.4863	0.7169
0.90999	3.233	0.4499	0.6636
0.93657	3.738	0.4166	0.6112
0.95738	4.395	0.3830	0.5551
0.97290	5.267	0.3490	0.4960
0.983797	6.448	0.3150	0.4352
0.990902	8.062	0.2814	0.3745
0.995112	10.222	0.2497	0.3176
0.997300	12.789	0.2232	0.2705
0.9981847	14.839	0.2072	0.2427
0.9989156	17.974	0.18822	0.2106
0.9994785	23.55	0.16442	0.17167
0.9998527	37.38	0.13050	0.11995
1		0	0

TABLE 2

a*, b* and δ* as a Function of $F(\rho)$

A Lagrangian interpolation is performed due to the non-linearity of the table.

It can be seen that although there are but 8 non-linear equations to be solved simultaneously, equations (10) through (29) must be solved simultaneously. This creates perturbations in the solution technique and does not always provide a perfect solution for each ball. However, the results are generally deemed adequate.

The preceding calculations have been necessary to establish data for calculation of the relative axial and radial displacements and the misalignment angle for each bearing. The force and moment equilibrium is also necessary for this solution. Equations (30) through (34) must be solved simultaneously to provide this information.

$$\sum_{j=1}^{j=z_h}\left[\frac{R_i K_{ij}\,\delta_{ij}^{1.5}\cos\psi_j}{X_{ij}}\right]_h \delta_{ah} - \left[\sum_{j=1}^{z_n}\frac{\frac{2(1-\lambda_j)M_{gj}}{D}R_i\cos^2\psi_j}{X_{ij}}\right]_h \delta_{rh} + \left[\sum_{j=1}^{j=z_h}\frac{K_{ij}\,\delta_{ij}\,R_i^2\cos^2\psi_j}{X_{ij}}\right]_h \theta_h =$$

$$M_h - \sum_{j=1}^{j=z_h}\left\{\left\{\frac{[K_{ij}(\overline{BD}\sin\alpha - W_j)\delta_{ij}^{1.5} - \frac{2(1-\lambda_j)M_{gj}}{D}(\overline{BD}\cos\alpha - V_j]R_i}{X_{ij}} + 2(1-\lambda_j)f_i M_{gj}\right\}\cos\psi_j\right\}_h \tag{30}$$

$$\left[\sum_{j=1}^{j=z_h}\frac{K_{ij}\,\delta_{ij}^{1.5}}{X_{ij}}\right]_h \delta_{ah} - \left[\sum_{J=1}^{j=z_h}\frac{\frac{2(1-\lambda_j)M_{gj}}{D}\cos\psi_j}{X_{ij}}\right]_h \delta_{rh} + \left[\sum_{j=1}^{j=z_h}\frac{K_{ij}\,\delta_{ij}^{1.5}R_i\cos\psi_j}{X_{ij}}\right]_h \theta_h = F_{ah} - \sum_{j=1}^{j=z_h}\left\{\frac{K_{ij}[\overline{BD}\sin\alpha - W_j]\delta_{ij}^{1.5}}{X_{ij}} - \frac{\frac{2(1-\lambda_j)M_{gj}}{D}[\overline{BD}\cos\alpha - V_j]}{X_{ij}}\right\}_h \tag{31}$$

$$\left[\sum_{j=1}^{j=z} \frac{\frac{2(1-\lambda_j)M_{gj}}{D}}{X_{ij}}\right]_h \delta a_h + \left[\sum_{j=1}^{z_h} \frac{K_{ij}\ \delta_{ij}^{1.5}\cos\psi_j}{X_{ij}}\right]_h \delta r_h +$$

$$\left[\sum_{j=1}^{j=z_h} \frac{\frac{2(1-\lambda_j)M_{gj}}{D}R_i\ \cos\psi_j}{X_{ij}}\right]_h \theta_h = F_{rh} - \sum_{j=1}^{j=z_h}\left\{\frac{K_{ij}(\overline{BD}\ \cos\alpha - V_j)\delta_{ij}^{1.5}}{X_{ij}} + \right.$$

$$\left.\frac{\frac{2(1-\lambda_j)M_{gj}}{D}(\overline{BD}\ \sin\alpha - W_j)}{X_{ij}}\right\}_h \tag{32}$$

$$F_{rh} = \frac{1}{\ell_{h-1}^3}\sum_{k=1}^{k=p} P_{h-1}{}^k(a_{h-1}{}^k)^2(3\ell_{h-1} - 2a_{h-1}) + \frac{1}{\ell_h^3}\sum_{k=1}^{k=q}$$

$$P_h{}^k(\ell_h - a_h{}^k)^2(\ell_h + 2a_h{}^k) + \frac{6}{\ell_{h-1}^3}\sum_{k=1}^{k=r} T_{h-1}{}^k a_{h-1}{}^k(\ell_{h-1} - a_{h-1}{}^k) - \tag{33}$$

$$\frac{6}{\ell_h^3}\sum_{k=1}^{k=s} T_h{}^k a_h{}^k(\ell_h - a_h{}^k) + 6E\left\{\frac{I_h - 1}{\ell_{h-1}^2}\left[\theta_{h-1} + \theta_h + \frac{2}{\ell_{h-1}}(\delta_{r,h-1} - \delta_{r,h})\right]\right.$$

$$\left. - \frac{I_h}{\ell_h^2}\left[\theta_h + \theta_{h+1} + \frac{2}{\ell_h}(\delta_{r,h} - \delta_{r,h+1})\right]\right\}$$

$$M_h = \frac{1}{\ell_{h-1}^2}\sum_{k=1}^{k=p} P_{h-1}{}^k(a_{h-1}{}^k)^2(\ell_{h-1} - a_{h-1}{}^k) - \frac{1}{\ell_h^2}\sum_{k=1}^{k=q} P_h{}^k a_h{}^k(\ell_h - a_h{}^k)^2$$

$$+ \frac{1}{\ell_{h-1}^2}\sum_{k=1}^{k=r} T_{h-1}{}^k a_{h-1}{}^k(2\ell_{h-1} - 3a_{h-1}{}^k)$$

$$- \frac{1}{\ell_h^2}\sum_{k=1}^{k=s} T_h{}^k(\ell_h - a_h{}^k)(\ell_h - 3a_h{}^k) \tag{34}$$

$$+ 2E\left\{\frac{I_{h-1}}{\ell_{h-1}}\left[\theta_{h-1} + 2\theta_h + \frac{3}{\ell_{h-1}}(\delta_{r,h-1} - \delta_{r,h})\right]\right.$$

$$+ \frac{I_h}{\ell_h} \left[2\theta_h + \theta_{h+1} + \frac{-3}{\ell_h} (\delta_{r,h} - \delta_{r,h+1}) \right] \Bigg\}$$

where, again, λ_j is 1 for outer raceway control and λ_j is 0 for inner raceway control. And $[\ ]_h$ or $\{\ \}_h$ means the values in $[\ ]$ or $\{\ \}$ are evaluated at bearing number h. Z_h is the total number of balls in bearing h, and equation (35) defines X_{ij}.

$$X_{ij} = (f_i - 0.5)D + \delta_{ij} \tag{35}$$

For a shaft/bearing system of NTS supports shown in Figure 4, equations (30) through (34) represent a system of 5 x NTS equations with δ_{ah}, δ_{rh}, θ_h, F_{rh}, and M_h for h = 1, 2, ... NTS, unknowns which are solved simultaneously.

If the solutions to equations (30) through (34) for δ_α, δ_r, and θ are not sufficiently close to the original guess, equations (8) through (35) are solved again until the old and new values agree.

The normal ball load is calculated by equations (36) and (37).

$$Q_{oj} = K_{oj} \ \delta_{oj}^{1.5} \tag{36}$$

$$Q \ = K_{ij} \ \delta_{ij}^{1.5} \tag{37}$$

The ball contact areas are related by equations (38) through (41).

$$A_{ij} = A_i^* \left\{ \frac{3Q_{ij}}{2(\Sigma\rho)_{ij}} \left[\frac{(1-\gamma_1^2)}{E_I} + \frac{(1-\gamma_2^2}{E_{II}} \right] \right\}^{1/3} \tag{38}$$

$$A_{oj} = A^* \left\{ \frac{3Q_{oj}}{2(\Sigma\rho)_{oj}} \left[\frac{(1-\gamma_1^2)}{E_I} + \frac{(1-\gamma_2^2}{E_{II}} \right] \right\}^{1/3} \tag{39}$$

$$b_{ij} = b_i^* \left\{ \frac{3Q_{ij}}{2(\Sigma\rho)_{ij}} \left[\frac{(1-\gamma_1^2)}{E_I} + \frac{(1-\gamma_2^2)}{E_{II}} \right] \right\}^{1/3} \tag{40}$$

$$b_{oj} = b_\varphi^* \left\{ \frac{3Q_{oj}}{2(\Sigma\rho)_{oj}} \left[\frac{(1-\gamma_1^2}{E_I} + \frac{1-\gamma_2^2)}{E_{II}} \right] \right\}^{1/3} \tag{41}$$

A check on the validity of the assumed race control is performed by evaluating equations (42) through (44).

$$E = \frac{II}{2S^2} \quad a^{*3} \tag{42}$$

$$s = a/b \tag{43}$$

$$Qm\ Am\ Em \cos(\alpha_i - \alpha_o) > Q_n\ A_n\ E_n \tag{44}$$

for outer raceway control, m = 0, n = i
for inner raceway control, m = i, n = o

The a, b, and Q are for the most heavily loaded ball in the bearing. If the inequality is not true, then the assumed race control is switched and the solution begins again with equation (1). If the test is not met for either race control, the problem is ill conditioned due to the input data and the program terminates. If equation (44) is valid, then the cage speed, ball spin to roll ratio and ball rotational speed are calculated by equations (45) through (47), respectively.

$$N_m = \left(\frac{W_m}{w} \right) n \tag{45}$$

Outer raceway control

$$\left[\frac{W_s}{W_{roll}} \right]_{oj} = -(1 + \gamma' \cos\alpha_{oj}) \tan(\alpha_{oj} - \beta_j) + \gamma' \sin\alpha_{oj} \tag{46}$$

Inner raceway control

$$\left[\frac{W_s}{W_{roll}} \right]_{ij} = -(1 + \gamma' \cos\alpha_{ij}) \tan(\alpha_{ij} - \beta_j) = \gamma' \sin\alpha_{ij}$$

$$\frac{N_{roll}}{N_o} = -\frac{1}{\gamma'} \tag{47}$$

For inner raceway rotation $N_o = -N$

The ball normal stress is calculated from equations (48) and (49).

$$\sigma_{ij} = \frac{3Q_{ij}}{\pi a_{ij} b_{ij}} \left[1 - \left(\frac{x}{a_{ij}}\right)^2 - \left(\frac{y}{b_{ij}}\right)^2 \right]^{1/2} \tag{48}$$

$$\sigma_{oj} = \frac{3Q_{oj}}{\pi a_{oj} b_{oj}} \left[1 - \left(\frac{x}{a_{ij}}\right)^2 - \left(\frac{y}{b_{ij}}\right)^2 \right]^{1/2} \tag{49}$$

where x and y are zero at the geometrical center of the ball. The shaft deflection calculation from equation (50) is for only one load, one torque and one moment arm. The value for x is given by equation (51).

$$\begin{aligned} E_h I_h Y_h = & - \frac{F_{rh}}{6} \left[\ell_h^2 (2\ell_h - 3x) + x^3 \right] + \frac{\left(M_h - T_h^k\right)}{2} (\ell_h - x)^2 \\ & + \frac{P_n^k}{6} \left[x^2 (x - 3a_h^k) - \ell_h^2 (3x + 3a_h^k - 2\ell_h) + 6 x \ell_h a_h^k \right] \\ & + E_h I_h \left[\delta_{r_{h+1}} - \theta_{h+1} (\ell_h - x) \right] \end{aligned} \tag{50}$$

$$x = \ell/2 \tag{51}$$

The bearing stiffness is given by equation (52).

$$L_h = 4.77 \times 10^6 \, Z_h \, D^{1/2} \cos^{5/2}\alpha \, \delta_{rh}^{1/2} \tag{52}$$

The minimum lubricant film thickness is related by equation (53).

$$\left(\frac{h_o}{R_x'}\right)^{2-\eta} = 12c \left[\frac{\mu_o \alpha_\mu U}{R_x'}\right] \left[\frac{a}{R_x'}\right] \left[\frac{3Q}{4E' b R_x'}\right]^{-\eta} \tag{53}$$

where c and η are given in Table 3, and equations (54), (55), and (56) are intermediate calculations.

$$R_x' = \left[\frac{2}{D} + \frac{2}{d_i} \right]^{-1} \tag{54}$$

$$E' = \left[\frac{1 - \gamma_1^2}{\pi E_I} + \frac{1 - \gamma_2^2}{\pi E_{II}}\right]^{-1} \tag{55}$$

$$U = 1/2 \ (U_{ball} + U_{raceway}) \tag{56}$$

s = a/b	c	η
2.0	0.065	0.548
1.0	0.088	0.620
0.5	0.095	0.642
0.2	0.098	0.648

TABLE 3

Lubricant Coefficients

The film thickness is affected by heating and is related by equations (57), (58) and (59).

$$h_{vh} = C_{vn} \ h_o \tag{57}$$

where

$$C_{vh} = \frac{3.94}{3.94 + L^{0.62}} \tag{58}$$

$$L = 1001 \ \frac{\mu_o \alpha_T U^2}{K} \tag{59}$$

The internal heat generation within the bearing can now be solved. The viscous friction torque is calculated from equation (60) or (61).

$$M_v = 2.91 \times 10^{-2} \ g_o \ (V_o n)^{2/3} \ dm^3 \tag{60}$$

$$Mv = 3.492 \times 10^{-3} \ g_o \ dm^3 \ (\text{for } V_o n \le 0.2) \tag{61}$$

	Mist. Lub.	Grease Lub.	Jet Lub.
Single Row	1	2	4

TABLE 4

Lubricant Torque Factor

The torque due to the applied load is determined from equations (62) and (63).

$$M_{\ell} = f, F_{\beta} \ d_m \tag{62}$$

$$f_1 = p \left(\frac{F_s}{C_s} \right)^q \tag{63}$$

For angular contact ball bearings,

$$p \approx 0.00115 \tag{64}$$

$$q \approx 0.33 \tag{65}$$

and F_{β} is the larger of the following two equations.

$$F_{\beta} = 0.9 \ F_{ah} \cot\alpha - 0.1 \ F_{rh} \tag{66}$$

$$F_{\beta} = F_{rh} \tag{67}$$

The torque resulting from ball spinning is related by equations (68) through (73).

$$M_{sj} = \frac{3\mu \ Q_{ij} \ a_{ij} \ E_{ij}}{8} \quad \text{for inner raceway control} \tag{68}$$

or

$$M_{sj} = \frac{3\mu \ Q_{oj} \ a_{oj} \ E_{oj}}{8} \quad \text{for outer raceway control} \tag{69}$$

$$E_{ij} = \frac{\pi}{2S_{ij}} \ a_{ij}{}^{*3} \tag{70}$$

$$E_{oj} = \frac{\pi}{2S_{oj}} \ a_{oj}{}^{*3} \tag{71}$$

$$S_{ij} = a_{ij}/b_{ij} \tag{72}$$

$$S_{oj} = a_{oj}/b_{oj} \tag{73}$$

The resulting heat generation from friction, applied load and ball spinning is given by equations (74) through (76), respectively, with the total heat given by equation (77).

$$H_\gamma = 0.0404\,\eta\,M_\gamma \tag{74}$$

$$H_\ell = 0.0404\,\eta\,M_\ell \tag{75}$$

$$H_{sj} = 0.0404\,\eta_{sj}\,M_{sj} \tag{76}$$

$$H_{total} = H_\gamma + H_\ell + \sum_{j-1}^{j=Z_h} H_{sj} \tag{77}$$

Although the purpose of BABHAP was to determine internal heat generation, a virtual dictionary of ball bearing behavior is described by the program.

NOMENCLATURE

A concerted effort was made to use unique mathematical symbols and abbreviations. However, the complexity and magnitude of the scope of these equations led to some duplication. Usually the duplication will be for an insignificant intermediate calculation.

		Units
a	Semi-major axis of the most heavily loaded ball of a bearing	in
a_{ij}	Semi-major axis of j^{th} ball inner raceway contact	in
a_{oj}	Semi-major axis of j^{th} ball outer raceway contact	in
a^*	Table 2	--
a_h^k	Figure 4	in
b	Semi-minor axis of the most heavily loaded ball of a bearing	in
b_{ij}	Semi-minor axis of j^{th} ball inner raceway contact	in
b_{oj}	Semi-minor axis of j^{th} ball outer raceway contact	in
b^*	Table 2	--
c_s	Basic static capacity	lb
$c_{\gamma h}$	Viscous heating correction factor, equation (58)	--
di	Inner raceway diameter of a bearing	in
do	Outer raceway diameter of a bearing	in
dm	Bearing pitch diameter, equation (6)	in
D	Ball diameter	in
E_I	Modulus of elasticity of ball	psi
E_{II}	Modulus of elasticity of bearing	psi
E_h	Modulus of elasticity of shaft h	psi
E'	$\left[\frac{1-\gamma_1^2}{\pi E_I} + \frac{1-\gamma_2^2}{\pi E_{II}}\right]^{-1}$, reduced modulus	psi
f_i	Equation (4)	--
f_o	Equation (4)	--
F_{ah}	Axial reaction force of bearing h	lb
F_{rh}	Radial reaction force of bearing h	lb
f_1	Equation (63)	--
F_β	Equation (66) or (67)	lb
F_s	Static equivalent load	lb

		Units
FC_j	Centrifugal force of j^{th} ball	lb
$\overline{BD}$	Distance between raceway groove curvature radii	in
$F(\rho)_{ij}$	Inner Raceway curvature difference of j^{th} ball	--
$F(\rho)_{oj}$	Outer raceway curvature difference of j^{th} ball	--
g_o	Table 4	--
h_o	Minimum film thickness without the consideration of viscous heating	in
$h_{\gamma h}$	Minimum film thickness	in
H_ℓ	Heat generation due to applied load	BTU/hr
H_γ	Heat generation due to friction	BTU/hr
H_{sj}	Heat generation due to ball spinning	BTU/hr
H_{total}	Total heat generation	BTU/hr
I_h	Moment of inertia of shaft h	in^4
J	Mass moment of inertia of ball	$in\text{-}lb\text{-}sec^2$
k	Thermal conductivity of lubricant	$BTU/hr/ft^{2\circ}$
K_{oj}	Load-deflection factor, equation (22)	$Lb\text{-}in^{1.5}$
K_{ij}	Load-deflection factor, equation (23)	$Lb\text{-}in^{1.5}$
ℓh	Span of shaft No. h, Figure 4	in
L	Load factor, equation (59)	--
m	Mass of ball	lbm
M_h	Reaction moment of bearing h	in-lb
M_ℓ	Torque due to applied load	in-lb
M_{gj}	Gyroscopic moment of j^{th} ball	in-lb
M_γ	Viscous friction torque	in-lb
M_{sj}	Torque due to j^{th} ball spinning	in-lb
n	rpm of rotating raceway	rpm
n_m	rpm of the cage	rpm
n_{roll}	Ball rolling speed	rpm
P_k	Equation (64)	--

		Units
P_h	Concentrate load to the shaft, Figure 4	lb.
q	Equation (65)	--
Q	Normal load of the most heavily loaded ball in a bearing	lb
Q_{ij}	Normal load between inner raceway and j^{th} ball	lb
Q_{oj}	Normal load between outer raceway and j^{th} ball	in
R_i	Radius of the locus of inner raceway groove curvature center	in
R_x^1	$\left[\frac{2}{D} + \frac{2}{d_i}\right]^{-1}$, equation (54)	in
S	a/b	--
S_{ij}	a_{ij}/b_{ij}	--
S_{oj}	a_{oj}/b_{oj}	--
S_{xj}	Equation (8), Figure 3	in
S_{zj}	Equation (9), Figure 3	in
$T_h{}^k$	Applied torque, Figure 4	in - lb
U	$1/2\ (U_{ball} + U_{raceway})$	in/sec
U_{ball}	Ball linear velocity	in/sec
$U_{raceway}$	Raceway linear velocity	in/sec
V_j	Equation (10) ~ equation (17), Figure 3	in
W_j	Equation (10) ~ equation (17), Figure 3	in
X_{ij}	$(f_i - 0.5)D + \delta_{ij}$	in
Z_h	Number of balls in bearing h	--
α	Initial contact angle prior to loading, Figure 3	rad
α_o	Free contact angle	rad
α_T	Temperature coefficient of viscosity	1/°R
α_μ	Pressure viscosity component	rad
α_{ij}	Contact angle between inner raceway and j^{th} ball, Figure 3	rad
α_{oj}	Contact angle between outer raceway and j^{th} ball, Figure 3	rad

		Units
β_j	j^{th} ball attitude angle	rad
γ'	D/dm	--
γ_{ij}	Equation (26)	--
γ_{oj}	Equation (27)	--
L_h	Bearing stiffness, Equation (52)	lb/ft
δ_a	Relative axial displacement	in
δ_r	Relative radial displacement	in
δ^*	Dimensionless contact deformation, Table 2	--
δ_{ij}	Contact deformation between j^{th} ball and inner raceway	in
δ_{oj}	Contact deformation between j^{th} ball and outer raceway	in
δ_{ij}^*	Dimensionless contact deformation at inner raceway	--
δ_{oj}^*	Dimensionless contact deformation at outer raceway	--
δ_{ah}	Relative axial displacement at bearing h	in
δ_{rh}	Relative radial displacement at bearing h	in
μ	Coefficient of friction (sliding)	--
μ_o	Lubricant viscosity at ambient temperature	lbm/ft·sec
ν_o	Kinematic viscosity of lubricant at ambient temperature	ft^2/sec
ν_1	Poisson's ratio of ball	--
ν_2	Poisson's ratio of raceway	--
θ	Misalignment angle	rad
θ_h	Misalignment angle of bearing h	rad
W	Angular speed of rotating raceway	rad/sec
W_m	Angular speed of cage or orbital speed of balls	rad/sec
W_R	Ball rotational speed	rad/sec
W_{roll}	Angular speed of ball rolling	rad/sec
W_s	Angular speed of spinning motion	rad/sec
$(\Sigma\rho)_{ij}$	Inner raceway curvature sum of j^{th} ball	in^{-1}

		Units
$(\Sigma\rho)_{oj}$	Outer raceway curvature sum of j^{th} ball	in^{-1}
ψ_j	Position angle of j^{th} ball	rad/sec
E_{ij}	Elliptic integral of 2nd kind, equation (70)	--
E_{oj}	Elliptic integral of 2nd kind, equation (71)	--
λ_j	Parameter	--

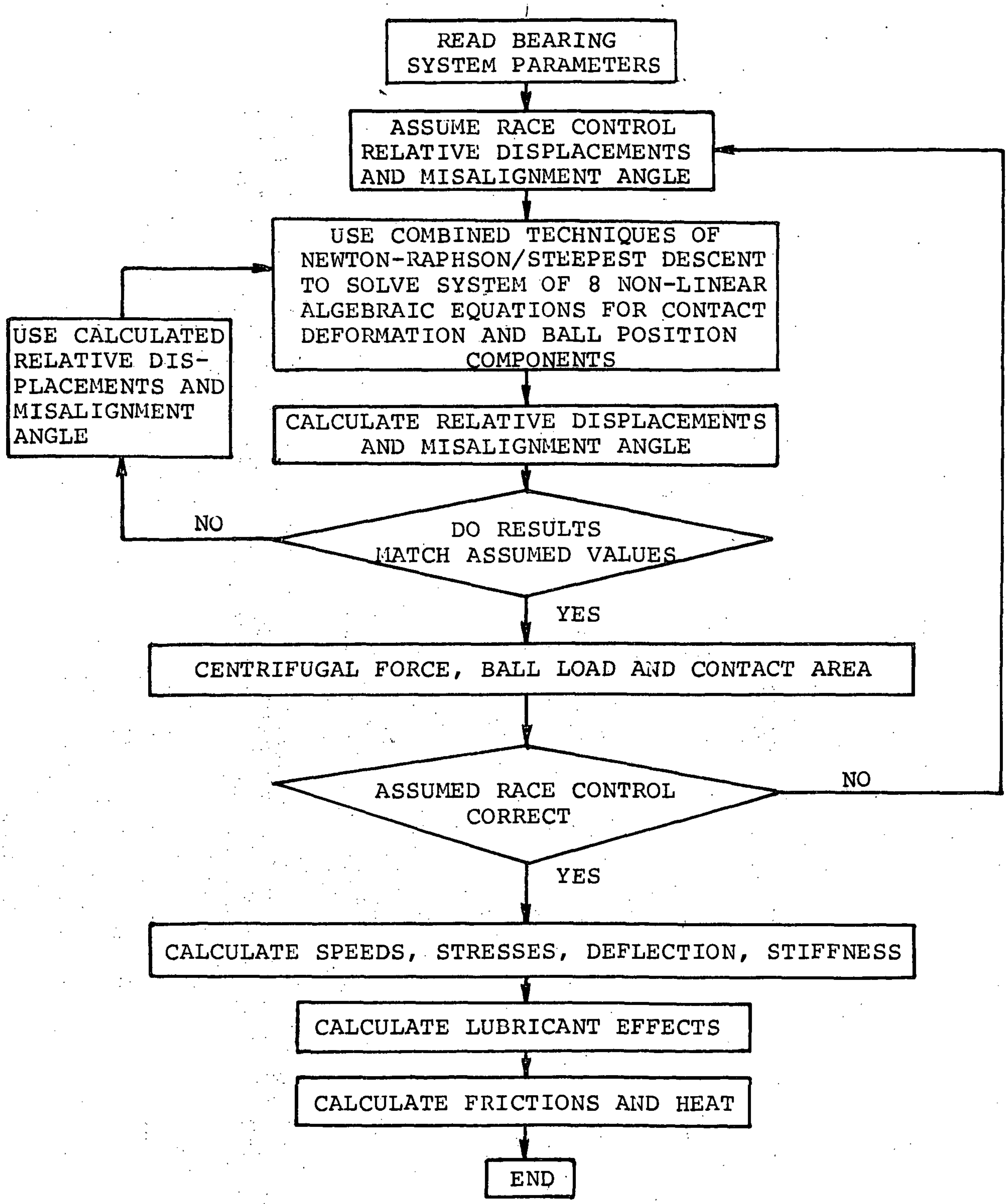


Figure 1. Major Sections of the Ball Bearing Heat Analysis Program

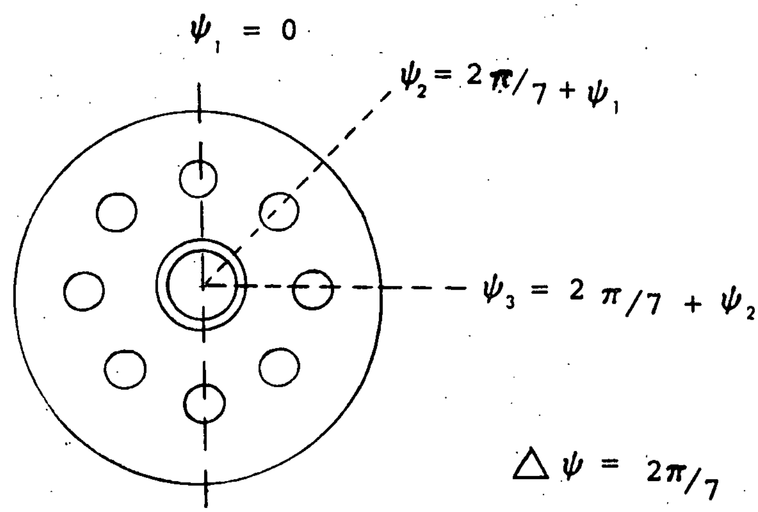


Figure 2. Typical Ball Bearing Position Definition

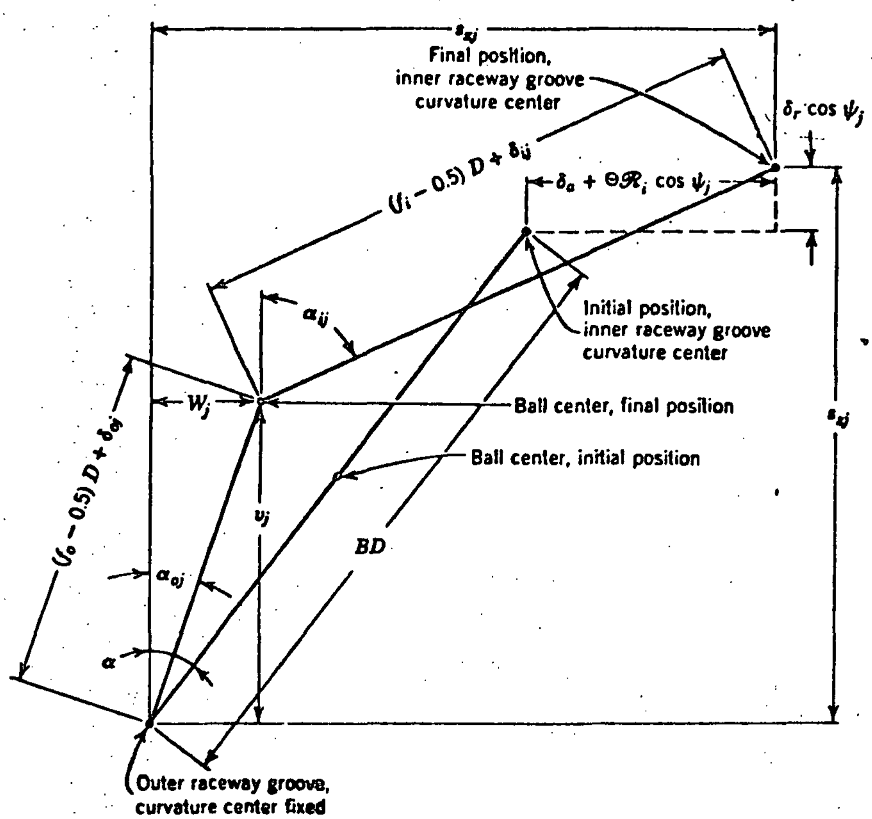


Figure 3. Positions of Ball Center and Raceway Groove Curvature Centers at Angular Position ψ, with and without Applied Load

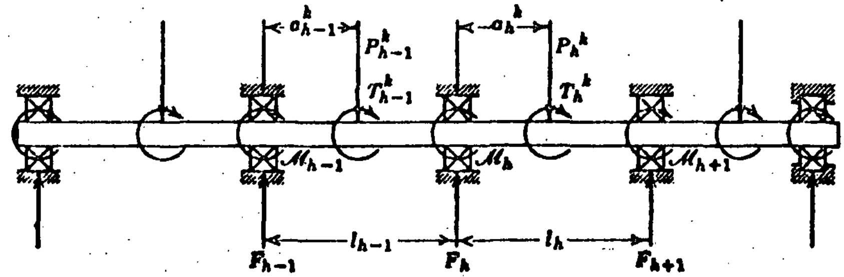


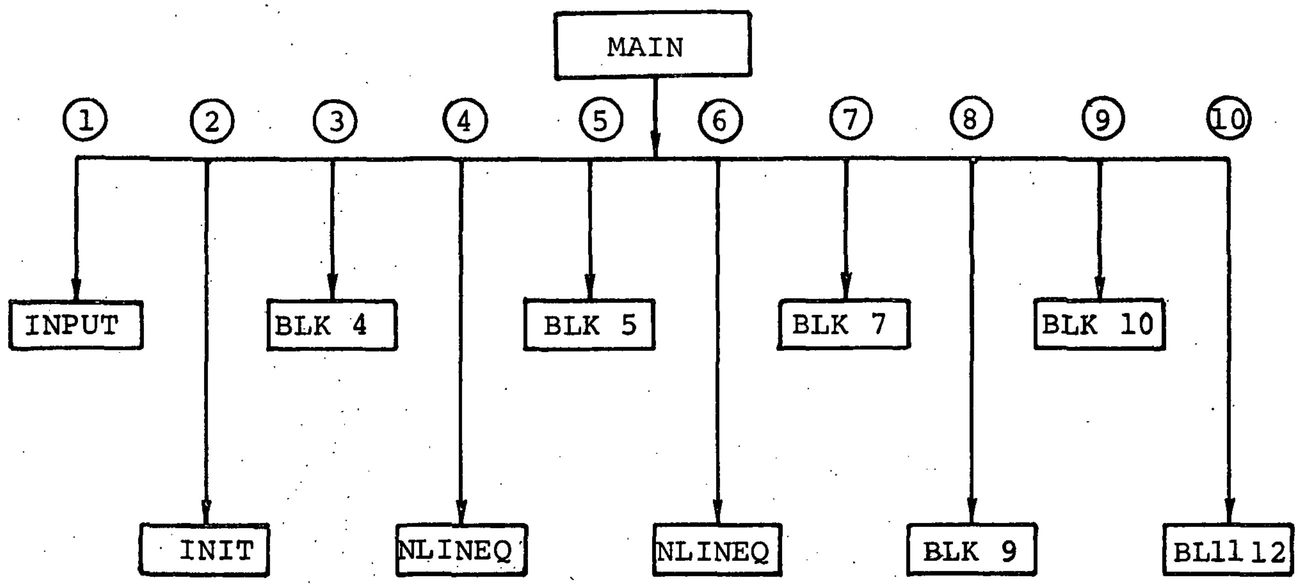
Figure 4. Multiple Bearing-Shaft System

PROGRAM BRIEFS

This section consists of short concise descriptions of the function of each routine in BABHAP.

ROUTINE MAIN

This routine (overlay) is the director for BABHAP, and calls all sub-programs (overlays on the PDP 11/45). Some equation evaluations are made in the routine to reduce the number of overlays necessary to fit on the PDP machine. All input and calculated data are transferred from MAIN to each overlay through labeled COMMON. The following diagram describes the solution sequence for BABHAP.



SOLUTION SEQUENCE FOR BABHAP

SUBROUTINE INPUT

This routine (overlay) reads all input data and converts it to the proper units. A page header is printed, followed by the input parameters. The routine is structured to reduce repetitive input for additional cases and to allow for chosen parameters to be set in the BLOCK DATA routine if desired.

SUBROUTINE INIT

Initial values are established for the non-linear equations in routine (overlay) INIT. The logic for specifying which raceway is controlled is also a part of INIT.

SUBROUTINE BLK4

The BLK4 routine (overlay) solves for the position of the inner raceway groove curvature center after the effects of the applied load, relative to the fixed outer raceway groove curvature center.

SUBROUTINE BLK5

The supportive equations necessary to find the relative axial displacement, relative radial displacement, and the misalignment angle are solved in the BLK5 routine (overlay).

SUBROUTINE BLK7

The calculations for normal ball load and the contact area for each ball comprise the BLK 7 routine (overlay).

SUBROUTINE BLK9

The cage and ball rotational speeds are calculated in routine (overlay) BLK9. The ball normal stress due to the inner and outer raceway point of contact are also calculated. Bearing stiffness is also determined in BLK9.

SUBROUTINE BLK10

The primary function of routine (overlay) BLK10 is to calculate the lubricant film thickness for the most heavily loaded ball. The film thickness is also evaluated for the inclusion of viscous heating on the lubricant.

SUBROUTINE BL1112

The BL1112 routine (overlay) calculates the viscous friction torque, torque due to the applied load, and torque as a result of ball spinning. The torque terms are then utilized to calculate the heat generation within each ball bearing, as a result of friction, load and ball spinning.

BLOCK DATA

The BLOCK DATA routine (overlay) establishes table values for label COMMON variables. The routine can be used to initialize or provide default input values for the more common materials, reducing the user input list. The structure of the input routine will allow overriding default data without program modifications.

SUBROUTINE NLINEQ

This subroutine (overlay) solves non-linear algebraic equations of the form

$$\bar{f}(\bar{x}) = \bar{0} \tag{1}$$

by combining the techniques of the Newton Raphson method with the method of steepest descent. The derivatives are approximated by differencing and the elements of the Jacobian are determined at each iteration

$$J_{kj} = \frac{\partial}{\partial X_j} f_k(\bar{X}) \tag{2}$$

A correction vector $\bar{\delta}$, is determined by solving the linear system of equations

$$\sum_{j=1}^{n} J_{kj}\, \delta_j = -f_k(X) \qquad k=1,\ 2,\ldots n \tag{3}$$

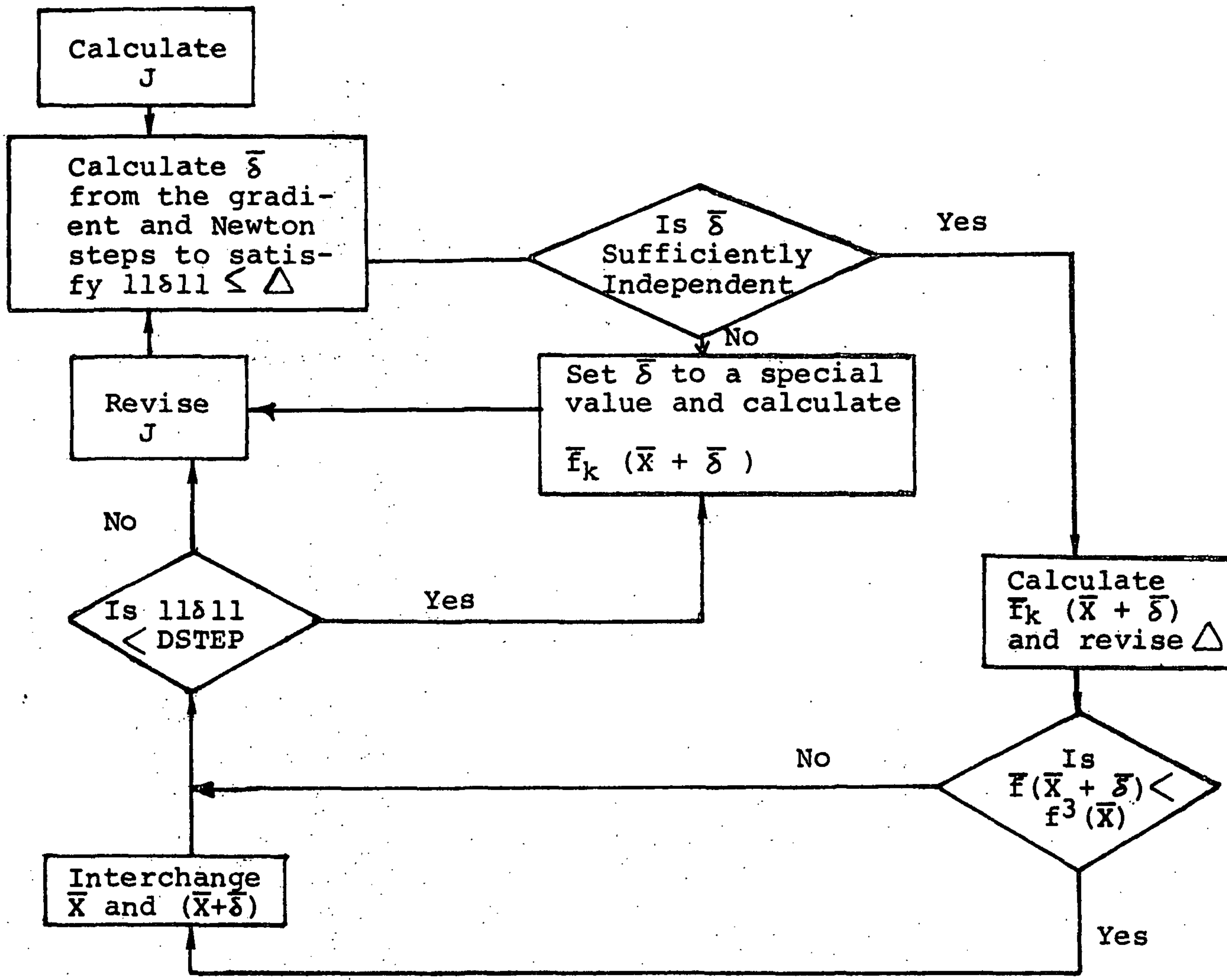
Then $\bar{X}$ is replaced with $(\bar{X} + \lambda\,\bar{\delta})$ where $\bar{X}$ initially is a guess, and λ is determined by a search process to make the estimate $(\bar{X} + \lambda\,\bar{\delta})$ better than the estimate $\bar{X}$.

The criterion for success of the search is

$$\bar{f}(\bar{X} + \lambda\,\bar{\delta}) < \bar{f}(\bar{X})$$

If the program predicts a singularity in the path of the solution, the method of steepest descent is used. This method allows the convergence to a stationary point which may not be a solution; if this occurs, another initial guess should be tried.

As with all Newton or steepest descent algorithms, the step size and initial guess are critical in finding solutions efficiently. The step length, Δ, is revised internally to be large or small to obtain a solution. However, the step length is not allowed to get smaller than the specified data input DSTEP. The following diagram describes the basic program flow.



Logic Diagram for NLINEQ

PARAMETER LIST

N	=	the number of simultaneous equations to be solved
X	=	one dimensional array of the unknowns
DSTEP	=	step length minimum bound
DMAX	=	maximum step length bound
ACC	=	specified accuracy for residuals
MAXFUN	=	limit for number of iterations
IPRINT	=	"0" for answer only, "1" for each iteration
F	=	one dimensional array of function values
AJINV	=	two dimensional array for inverse Jacobian
W	=	one dimensional working space $2N^2 + 5N$
JC	=	one dimensional working space

SUBROUTINE CALFUN

This subroutine defines the non-linear set of equations

$$\overline{f}(\overline{X}) = \overline{0}$$

to be solved by the NLINEQ routine. CALFUN resides in the BABHAP library on the PDP 11/45. The parameters N, X, F are the same as in subroutine NLINEQ.

SUBROUTINE GJR

This is a supportive routine for NLINEQ, and resides in the BABHAP library on the PDP 11/45. GJR solves simultaneous linear equations by using Gauss-Jordan elimination with column pivoting. The parameters are supplied by NLINEQ and therefore deleted from this documentation.

SUBROUTINE LAGRAN

This subroutine is supportive and resides in the BABHAP library on the PDP 11/45. LAGRAN uses the lagrangian interpolation formula to find the value of

$$Y = F(X)$$

The technique uses a skip search to accelerate finding the desired data, and provides accurate results for non-linear tables.

INPUT PARAMETERS

The input parameters for BABHAP have primarily been limited to the physical properties of the system - shaft, balls, raceway, and lubricant. The remainder of the parameters are related to the applied loads. Although there are 26 possible input cards, BABHAP has been coded to allow the analyst to select as few as one input card to run repetitive cases, or to specify any or all inputs in

the BLOCK DATA routine without modifying any other segments of the program. Figure 1 is a sample list of the input data. The required formats and variable names are given in Figure 2.

```
@RUN BBWEA2,1WEP452E7010,SHULTZBIN214,30,500/2000
@ASG,T IN,T,23206
@ASG,T BAB,F///1000
@COPY,G IN.,BAB.
@ADD,P BAB.BABHAP
@MAP,IS SYM,ABS
 LIB SYS$*MSFC$.
@XQT ABS
     1
              1
.4375
              2
2.1225
              3
2.9975
              4
29600000.
              5
29600000.
              6
29600000.
              7
20.
              8
0.0116
              9
.000128
             10
60.
             11
0.0028
             12
.3
             13
.3
             14
5000.
```

Figure 1. Sample Run Stream and Data Input for BABHAP.

```
                15
                 1
      1200.
                16
      .7854
                17
      483.84
                18
      30.
                19
      7.
                20
      1000.
                21
      700.
                22
                 1
      1.0
                23
                13
                24
                 4
      .02
                25
                 1
                26
                 1
      15.
        999
      OFIN
```

Figure 1. Sample Run Stream and Data Input for BABHAP (Continued)

Page 2 of 2

Column No.	Value/Format		Parameter Name/Definition
5	1 (I5)		NTS = number of bearing support points
10	1 (I10)		Indicates that the ball diameters follow
8 fields of 10	E10.0		D(I) (I = 1 to NTS)
10	2 (I10)		Indicates inner raceway diameter follows
8 fields of 10	E10.0		DI(I)
10	3 (I10)		Indicates outer raceway diameter follows
8 fields of 10	E10.0		DO(I)
10	4 (I10)		Indicates ball modulus of elasticity follows
8 fields of 10	E10.0		E1(I)
10	5 (I10)		Indicates race modulus of elasticity follows
8 fields of 10	E10.0		E2(I)
10	6 (I10)		Indicates shaft modulus of elasticity follows
8 fields of 10	E10.0		EH(I)
10	7 (I10)		Indicates bearing contact angle follows
8 fields of 10	E10.0		ALPHA(I)
10	8 (I10)		Indicates temperature coefficient for viscosity follows
8 fields of 10	E10.0	*	ALPHAT(I)
10	9 (I10)		Indicates pressure coefficient for viscosity follows
8 fields of 10	E10.0	*	ALPHMU (I)
1,2	10 (I10)		Indicates the density of the lubricant follows
8 fields of 10	E10.0		DENSL(I)

Figure 2. Input Names and Formats Page 1 of 3

Column No.	Value/Format	Parameter Name/Definition
9,10	11 (I10)	Indicates lubricant kinematic viscosity follows
8 fields of 10	E10.0	NUO(I)
9,10	12 (I10)	Indicates ball Poisson's ratio follows
8 fields of 10	E10.0	NU1(I)
9,10	13 (I10)	Indicates raceway Poisson's ratio follows
8 fields of 10	E10.0	NU2(I)
9,10	14 (I10)	Indicates the bearing basic static capacity follows
8 fields of 10	E10.0	CS(I)
9,10	15 (I10)	Indicates the number and value of concentrated loads to the shaft follow
10	1 (I10)	Temporarily limited to "1"
8 fields of 10	E10.0	PH(I,K) (K = 1)
9,10	16 (I10)	Indicates the shaft moment of inertia follows
8 fields of 10	E10.0	IH(I)
9,10	17 (I10)	Indicates the ball density follows
8 fields of 10	E10.0	DENSB(I)
9,10	18 (I10)	Indicates the shaft span follows
8 fields of 10	E10.0	LH(I)
9,10	19 (I10)	Indicates lubricant thermal conductivity
8 fields of 10	E10.0	KH(I)
9,10	20 (I10)	Indicates the RPM of the rotating raceway follows
8 fields of 10	E10.0	NH(I)

Figure 2 (Continued)

Column No.	Value/Format	Parameter Name/Definition
9,10	21 (I10)	Indicates bearing thrust load follows
8 fields of 10	E10.0	FAH(I)
9,10	22 (I10)	Indicates the number of applied torques to the shaft and their values follow
10	1 (I10)	Temporarily limited to "1"
8 fields of 10	E10.0	TH(I,K) (K=1)
9,10	23 (I10)	Indicates bearing number of balls follows
8 fields of 10	I10	ZH(I)
9,10	24 (I10)	Indicates lubricant type and sliding friction coefficients follow
8 fields of 10	I10	LTYPE(I) (0,1,2,4 indicates none, mist, grease, jet, respectively)
8 fields of 10	E10.0	MU(I)
9,10	25 (I10)	Indicates the pointer for rotating raceway follows
10	I10	IRRC (0,1 for outer, inner, respectively)
9,10	26 (I10)	Indicates the number and value of shaft torque arm lengths follow
10	1 (I10)	Temporarily limited to "1"
8 fields of 10	E10.0	AH(I,K) (K=1)
Blank Card		Indicates end of case
1 through 5	99999	Indicates End of Job

* Indicates this data will be determined from Table interpolation at some later date.

Figure 2 (Continued) Page 3 of 3

REFERENCES

1. Harris, Tedric A., Rolling Bearing Analysis, John Wiley & Sons, Inc., 1966.

2. Murch, L. E. and Wilson, W. R. D., "A Thermal Elastohydrodynamic Inlet Zone Analysis," Journal of Lubrication Technology, April 1975.

3. Cheng, H. S., "A Numerical Solution of the Elastohydrodynamic Film Thickness in an Elliptical Contact," Journal of Lubrication Technology, January 1970.

APPENDIX

COMPUTER LISTING OF BABHAP

```
@RUN V3S101,1HEH14492920,SHULTZ8IN214,30,1000

@MSG,W          REMOVE AT CARD READER     12-04-78        CLOCK NO 6454

@ASG,T IN.,U,10964

@ASG,T SYM.,F///200

@REWIND IN.
FURPUR 27R3DL33 SL73R1 12/04/78 19:26:31

@COPY,G IN.,SYM.
SOLARHBIN214*BAB(0) COPIED ON 12/05/77 AT 22:27:01
    40 BLOCKS COPIED.
EOF ENCOUNTERED ON INPUT TAPE

@PRT,S SYM.BABHAP
```

```
SHULTZ3IN214*SYM(0).BA3HAP
      @FOR,IS MAIN,MAIN
C     MAIN LINE DIRECTOR FOR BA3HAP (BALL BEARING HEAT ANALYSIS PROGRAM)
C     DEVELOPED FOR MSFC MATERIALS AND PROCESSES LAB BY WYLE LABS
C     BILL SCHULTZ PROGRAMMER * JIM CHIOU ENGINEER
C     ROLLER BEARING ANALYSIS PROGRAM TO DETERMINE TOTAL HEAT GENERATIONBA300300
C        WITHIN A BALL BEARING DUE TO FRICTION,APPLIED LOAD AND BALL    BA300400
C     A VARIABLE NAME IS ASSIGNED TO THE CARD READER (ICR) AND TO THE   BA300500
C        LINE PRINTER (LPT) TO ENHANCE MOBILITY OF THE PROGRAM FOR      BA300700
C        VARIOUS MACHINES                                               BA300800
      COMMON /LB1/
     $               ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAI( 4)         BA300900
     1,              ALPHMU( 4)     ,MUO( 4)        ,MUO( 4)            BA301000
     2,              MUI( 4)        ,MU2( 4)        ,D( 4)              BA301100
     4,              DI( 4)         ,DO( 4)         ,E1( 4)             BA301200
     4,              E2( 4)         ,EH( 4)         ,CS( 4)             BA301300
     4,              FS( 4)         ,PH( 4, 4)      ,LH( 4)             BA301400
     6,              KH( 4)         ,NH( 4)         ,FAH( 4)            BA301500
     7,              IH( 4)         ,JH( 4)         ,ZH( 4)             BA301600
     8,              SLH( 4)        ,TH( 4, 4)      ,DELA( 4)           BA301700
     9,              DELR( 4)       ,THETA( 4)      ,OMEAN( 4)          BA301800
     T,              GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 8)          BA301900
     1,              FI( 4)         ,FO( 4)         ,BOBAR( 4)          BA302000
     2,              R( 4)          ,M( 4)          ,NIS
      COMMON /LB2/
     $               PSI( 4,16)     ,ALPHAO( 4,16) ,ALPHAI( 4,16)       BA302200
     1,              BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)       BA302300
     2,              MG( 4,15)      ,SX( 4,16)     ,SZ( 4,16)           BA302400
     4,              FC( 4,15)      ,GAMMAI( 4,16) ,GAMMAO( 4,16)       BA302500
     4,              SIGMAI( 4,16)  ,SIGMAO( 4,15) ,FRHOO( 4,16)        BA302600
     4,              FRHOI( 4,16)   ,OSTARO( 4,16) ,KO( 4,16)           BA302700
     6,              KI( 4,15)      ,OSTARI( 4,16) ,W( 4,16)            BA302800
     7,              DELO( 4,16)    ,DELI( 4,16)                        BA302900
      COMMON /LB3/
     $               FTAB(23)       ,ATAB(23)       ,BTAB(23)           BA303000
     1,              DTAB(23)                                           BA303100
      COMMON /LB4/
     $               DO( 4,15)      ,DI( 4,16)     ,ASTARI( 4,16)       BA303200
     1,              ASTARO( 4,16)  ,AI( 4,16)     ,AO( 4,16)           BA303300
     2,              BSTARI( 4,16)  ,BSTARO( 4,15) ,BI( 4,15)           BA303400
     4,              BO( 4,15)      ,EPSIO( 4,16)  ,EPSII( 4,16)        BA303500
     4,              DAEI( 4,16)    ,DAEO( 4,16)                        BA303600
     7,              W(4,16)        ,SUM( 4,5,4)   ,KI( 4,15)           BA303900
     8,              NPL( 4)        ,NIL( 4)       ,NAH( 4)             BA304000
     9,              AH( 4, 4)      ,VM( 4)        ,DSOOR( 4,16)        BA304100
      COMMON /LB5/
     $               NO( 4)                                             BA304200
     1,              EIY( 4)                       ,DELAH( 4)           BA304300
     2,              DELRH( 4)      ,THETAH( 4)    ,FRH( 4)             BA304400
     4,              MH( 4)         ,RXP( 4)       ,EP( 4)              BA304500
     4,              UB( 4)         ,UR( 4)        ,U( 4)               BA304600
     4,              IMO( 4)        ,JMO( 4)       ,IMI( 4)             BA304700
     6,              JMI( 4)        ,OMAXI( 4)     ,OMAXO( 4)           BA304800
     7,              ICHANG( 4)     ,SI( 4,15)     ,SO( 4,15)           BA304900
     8,              HO( 4)         ,IRC( 4)       ,HVH(4)              BA305000
      COMMON /LB6/
     1               STAB(4)        ,CTAB(4)       ,AETAT3(4)
```

```
      COMMON /LB37/
     $           LTYPE( 4)      ,FBETA( 4)     ,ICO(4)              BA305300
     $,          HF( 4)         ,HL( 4)        ,HS( 4)              BA305400
     $,          HTOTAL( 4)                                         BA305500
     $,          MV( 4)         ,ML( 4)        ,MJ(4)
     1,          MS( 4,16)      ,NS( 4,16)     ,LAMBDA( 4)
      COMMON /LB38/ ICR,LPT,SP,SQ,PI
      COMMON /NLIN/
     $           X(20)          ,F(20)         ,AJINV(20,20)
     1,          WORK(950)      ,JC(20)        ,ISYS
     $,          N              ,I             ,J
      COMMON /SLOAD/
     1           SELX( 5)       ,SELY( 5)      ,SELALP( 5)
      DOUBLE PRECISION X,F,AJINV,WORK
      REAL MV,ML,MJ,MS,NS,LAMBDA,NM,MH,NO
      REAL MUD,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI                BA305700
      INTEGER ZH                                                    BA305600
      TAN(Q)=SIN(Q)/COS(Q)                                          BA308400
      COT(Q)=COS(Q)/SIN(Q)                                          BA308500
    1 READ(ICR,1001)NTS
      IF(NTS.GT.3) GO TO 999                                        BA308700
      CALL INPUT
  300 CONTINUE                                                      BA321100
      IPASS=0
      CALL INIT
  400 CONTINUE                                                      BA325300
      IPASS=IPASS+1
      IF(IPASS.GT.2) GO TO 700
      DO 450 I=1,NTS                                                BA326400
      N3=ZH(I)                                                      BA326500
      DO 450 J=1,N3                                                 BA326500
      CALL BLK4
C USE COMBINED TECHNIQUES OF NEWTON-RAPHSON AND STEEPEST DESCENT TO  BA331200
C        SOLVE FOR THE VALUES OF V(I,J),W(I,J),DELO(I,J),DELI(I,J)  BA331300
      IRKNT=0
  410 IRET=0
      IRKNT=IRKNT+1
      N=8
      IF((J.GT.1).AND.(IRKNT.EQ.1)) GO TO 401
      GO TO 402
  401 CONTINUE
      X(1)=V(I,J-1)
      X(2)=W(I,J-1)
      X(3)=DELO(I,J-1)
      X(4)=DELI(I,J-1)
      X(5)=MS(I,J-1)
      X(6)=ALPHAI(I,J-1)
      X(7)=ALPHAO(I,J-1)
      X(8)=FC(I,J-1)
      GO TO 403
  402 CONTINUE
      X(1)=V(I,J)                                                   BA331900
      X(2)=W(I,J)                                                   BA332000
      X(3)=DELO(I,J)                                                BA332100
      X(4)=DELI(I,J)                                                BA332200
      X(5)=MS(I,J)
      X(6)=ALPHAI(I,J)
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      X(7)=ALPHAO(I,J)
      X(8)=FC(I,J)
  403 CONTINUE
      GAMMAI(I,J)=(D(I)*COS(X(6)          ))/DMEAN(I)                   BA329100
      GAMMAO(I,J)=(D(I)*COS(X(7)          ))/DMEAN(I)                   BA329200
      SIGMAO(I,J)=(1./D(I))*(4.-(1./FO(I))+((2.*GAMMAO(I,J))/(1.-       BA329300
     1GAMMAO(I,J))))                                                    BA329400
      SIGMAI(I,J)=(1./D(I))*(4.-(1./FI(I))+((2.*GAMMAI(I,J))/(1.-       BA329500
     1GAMMAI(I,J))))                                                    BA329600
      FRHOO(I,J)=((1./FO(I))+(2.*GAMMAO(I,J))/(1.-GAMMAO(I,J)))/(4.-    BA329900
     1 (1./FO(I))+(2.*GAMMAO(I,J))/(1.-GAMMAO(I,J)))                    BA330000
      FRHOI(I,J)=((1./FI(I))+(2.*GAMMAI(I,J))/(1.-GAMMAI(I,J)))/(4.-    BA330100
     1 (1./FI(I))+(2.*GAMMAI(I,J))/(1.-GAMMAI(I,J)))                    BA330200
C SET DSTAR USING LAGRANGIAN INTERPOLATION                              BA330300
      CALL LAGRAN(FRHOO(I,J),FTAB,DTAB,23,3,DSTARO(I,J),NERR)           BA330400
      IF(NERR.EQ.2) WRITE(LPT,2005) FRHOO(I,J)                          BA330500
      KO(I,J)=(1.8856*SIGMAO(I,J)**(-.5)*DSTARO(I,J)**(-1.5))/          BA330600
     1((1.-NU1(I)**2)/E1(I)+(1.-NU2(I)**2)/E2(I))                       BA330700
      CALL LAGRAN(FRHOI(I,J),FTAB,DTAB,23,3,DSTARI(I,J),NERR)           BA330800
      IF(NERR.EQ.2) WRITE(LPT,2007) FRHOI(I,J)                          BA330900
      KI(I,J)=(1.8856*SIGMAI(I,J)**(-.5)*DSTARI(I,J)**(-1.5))/          BA331000
     1((1.-NU1(I)**2)/E1(I)+(1.-NU2(I)**2)/E2(I))                       BA331100
      IF(IRC(I).EQ.1) GO TO 420
      BETA(I,J)=ATAN(SIN(X(7))/(COS(X(7)+GAMMAP(I))))
      GO TO 421
  420 BETA(I,J)=ATAN(SIN(X(6))/(COS(X(6)-GAMMAP(I))))
  421 CONTINUE
      TS1=(COS(X(7))+TAN(BETA(I,J))*SIN(X(7)))/(1.+GAMMAP(I)*COS(X(7)))
      TS2=(COS(X(6))+TAN(BETA(I,J))*SIN(X(6)))/(1.-GAMMAP(I)*COS(X(6)))
      OMROOM(I,J)=1./((TS1+TS2) *GAMMAP(I)*COS(BETA(I,J)))
      IF(IRRC(I).EQ.1) OMROOM(I,J)=-1.*OMROOM(I,J)
      IF((IRC(I).EQ.1).AND.(IRRC(I).EQ.1)) OMMOOM(I,J)=(COS(X(6)-X(7))-
     1GAMMAP(I)*COS(X(7)))/(1.+COS(X(6)-X(7)))
      IF((IRC(I).EQ.1).AND.(IRRC(I).EQ.0)) OMMOOM(I,J)=(1.+GAMMAP(I)*
     1COS(X(7)))/(1.+COS(X(6)-X(7)))
      IF((IRC(I).EQ.0).AND.(IRRC(I).EQ.1)) OMMOOM(I,J)=(1.-GAMMAP(I)*
     1COS(X(6)))/(1.+COS(X(6)-X(7)))
      IF((IRC(I).EQ.0).AND.(IRRC(I).EQ.0)) OMMOOM(I,J)=(COS(X(6)-X(7))+
     1GAMMAP(I)*COS(X(6)))/(1.+COS(X(6)-X(7)))
      ISYS=1                                                            BA332300
      CALL NLINEQ
      IF(ABS(X(1)-V(I,J)).GT.ABS(V(I,J))*0.05) IRET=1
      IF(ABS(X(2)-W(I,J)).GT.ABS(W(I,J))*0.05) IRET=1
      IF(ABS(X(3)-DELO(I,J)).GT.ABS(DELO(I,J))*0.05) IRET=1
      IF(ABS(X(4)-DELI(I,J)).GT.ABS(DELI(I,J))*0.05) IRET=1
      IF(ABS(X(5)-MS(I,J)).GT.ABS(MS(I,J))*0.05) IRET=1
      IF(ABS(X(6)-ALPHAI(I,J)).GT.ABS(ALPHAI(I,J))*0.05) IRET=1
      IF(ABS(X(7)-ALPHAO(I,J)).GT.ABS(ALPHAO(I,J))*0.05) IRET=1
      IF(ABS(X(8)-FC(I,J)).GT.ABS(FC(I,J))*0.05) IRET=1
      V(I,J)=X(1)                                                       BA332500
      W(I,J)=X(2)                                                       BA332600
      DELO(I,J)=X(3)                                                    BA332700
      DELI(I,J)=X(4)                                                    BA332800
      MS(I,J)=X(5)
      ALPHAI(I,J)=X(6)
      ALPHAO(I,J)=X(7)
      FC(I,J)=X(8)
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      IF(IRANT.GT.5) GO TO 411
      IF(IRET.EQ.1) GO TO 410
  411 CONTINUE
      WRITE(LPT,3003) I,J,ALPHAO(I,J),ALPHAI(I,J),BETA(I,J),OMMOON(I,J),BA328500
     1OMROOM(I,J)                                                      BA328600
      WRITE(LPT,3004)MG(I,J),SX(I,J),SZ(I,J),FC(I,J),GAMMAI(I,J),      BA329700
     1GAMMAO(I,J),SIGMAO(I,J),SIGMAI(I,J)                              BA329800
      WRITE(LPT,3005) FRHOO(I,J),FRHOI(I,J),OSTARO(I,J), OSTARI(I,J),  BA331600
     1 KO(I,J),KI(I,J)                                                 BA331700
      WRITE(LPT,3007)I,J,V(I,J),W(I,J),DELO(I,J),DELI(I,J),MG(I,J),
     1ALPHAI(I,J),ALPHAO(I,J)
  450 CONTINUE                                                         BA333000
      CALL BLK5
      N=5*NTS
      DO 565 I=1,NTS                                                   BA341300
      X(I)=DELAH(I)                                                    BA341400
      X(NTS+I)=DELRH(I)                                                BA341500
      X(2*NTS+I)=THETAH(I)                                             BA341600
      X(3*NTS+I)=FRH(I)                                                BA341700
      X(4*NTS+I)=MH(I)                                                 BA341800
  565 CONTINUE                                                         BA341900
      ISYS=2                                                           BA342100
      CALL NLINEQ
      DO 570 II=1,NTS                                                  BA342300
      DELAH(II)=X(II)                                                  BA342400
      DELRH(II)=X(NTS+II)                                              BA342500
      THETAH(II)=X(2*NTS+II)                                           BA342600
      FRH(II)=X(3*NTS+II)                                              BA342700
      MH(II)=X(4*NTS+II)                                               BA342800
      WRITE(LPT,3015)DELAH(II),DELRH(II),THETAH(II),FRH(II),MH(II)     BA342900
  570 CONTINUE                                                         BA343000
C COMPARE THE NEW VALUES WITH OLD AND RECALCULATE IF CHANGE IS GREATER BA343100
C         THAN 5 PER CENT                                              BA343200
  500 CONTINUE                                                         BA343300
      DO 601 II=1,NTS
      IF(ABS(DELAH(II)-DELA(II)).GT.(0.05*ABS(DELA(II)))) GO TO 605    BA343400
      IF(ABS(DELRH(II)-DELR(II)).GT.(0.05*ABS(DELR(II)))) GO TO 605    BA343500
      IF(ABS(THETAH(II)-THETA(II)).GT.(0.05*ABS(THETA(II)))) GO TO 605 BA343600
  601 CONTINUE
      GO TO 700                                                        BA343700
  605 CONTINUE                                                         BA343800
      DO 610 I=1,NTS                                                   BA343900
      DELA(I)=DELAH(I)                                                 BA344000
      DELR(I)=DELRH(I)                                                 BA344100
      THETA(I)=THETAH(I)                                               BA344200
  610 CONTINUE                                                         BA344300
      GO TO 400                                                        BA344400
  700 CONTINUE                                                         BA344500
C CALCULATE CONTACT ANGLE OF EACH BALL (0 TO 90 DEGREES ONLY)          BA344600
      CALL BLK7
C CHECK TO SEE IF RACE CONTROL SHOULD BE SWITCHED                      BA349300
      DO 850 I=1,NTS                                                   BA349400
      N3=Z4(I)                                                         BA349500
      DO 850 J=1,N3                                                    BA349600
      EPSIO(I,J)=(PI/(2.*(AO(I,J)/BO(I,J))**2))*ASTARO(I,J)**3         BA349700
      EPSII(I,J)=(PI/(2.*(AI(I,J)/BI(I,J))**2))*ASTARI(I,J)**3         BA349800
      QALI(I,J)=QI(I,J)*AI(I,J)*EPSII(I,J)                             BA349900
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      QAEO(I,J)=QO(I,J)*AO(I,J)*EPSIO(I,J)                            BA350000
      IF(IRC(I).EQ.1) GO TO 840
  830 CONTINUE                                                        BA350200
C OUTER RACE CONTROL                                                   BA350300
      DIFF=QAEO(I,J)*COS(ALPHAI(I,J)-ALPHAO(I,J))-QAEI(I,J)           BA350400
      IF(DIFF.LT.0.) GO TO 831                                        BA350500
      GO TO 850                                                       BA350600
  831 CONTINUE                                                        BA350700
      WRITE(LPT,2008)I,J,DIFF,QAEO(I,J),QAEI(I,J),ALPHAI(I,J),ALPHAO(I,JBA350800
     1)                                                               BA350900
      IF(QMAXO(I).LT.(QO(I,J)+1.LE-8)) WRITE(LPT,2009)
      GO TO 850                                                       BA351100
  840 CONTINUE                                                        BA351200
C INNER RACE CONTROL                                                   BA351300
      DIFF=QAEI(I,J)*COS(ALPHAI(I,J)-ALPHAO(I,J))-QAEO(I,J)           BA351400
      IF(DIFF.LT.0.)GO TO 841                                         BA351500
      GO TO 850                                                       BA351600
  841 CONTINUE                                                        BA351700
      WRITE(LPT,2010)I,J,DIFF,QAEO(I,J),QAEI(I,J),ALPHAI(I,J),ALPHAO(I,JBA351800
     2)                                                               BA351900
      IF(ICO(I).EQ.0) ICHANG(I)=1                                     BA352000
      IF(ICO(I).EQ.1) ICHANG(I)=0                                     BA352100
      IF(QMAXI(I).LT.(QI(I,J)+1.0E-8)) WRITE(LPT,2011)
  850 CONTINUE                                                        BA352300
      DO 860 I=1,NTS                                                  BA352400
      NOC=NOC+1                                                       BA352500
      IF(NOC.GT.(2*NTS)) GO TO 999                                    BA352600
      IF((ICO(I).EQ.0).AND.(ICHANG(I).EQ.1)) GO TO 300                BA352700
  860 CONTINUE                                                        BA352800
C ALL BEARINGS ARE ASSUMED TO HAVE THE SAME RACE CONTROL               BA352900
C CALCULATE CAGE SPEED BASED ON THE SPEED OF BALL 1,PSI=0              BA353000
      CALL BLK9
C CALCULATE MINIMUM FILM THICKNESS FOR MAXIMUM LOAD BALL               BA357700
      CALL BLK10
C  CALCULATE HEAT GENERATION DUE TO BALL SPINNING, LOAD, AND VISCOUS EFFECTS
      CALL BL1112
      GO TO 1                                                         BA366300
  999 CONTINUE                                                        BA366400
      WRITE(LPT,9991) NOC                                             BA366500
 9991 FORMAT(1X,46HTHE NUMBER OF CHANGES FOR CONTROLLED RACEWAY =I4)  BA366600
 1000 FORMAT(8I10)                                                    BA366700
 1001 FORMAT(2I5)
 2006 FORMAT(1X, 7HFRHOO =1PE13.6,23H IS OUTSIDE TABLE RANGE)         BA368300
 2007 FORMAT(1X,7HFRHOI =1PE13.6,23H IS OUTSIDE TABLE RANGE)          BA368400
 2008 FORMAT(1X,14HBEARING NUMBER,I2,9X,11HBALL BUMBER,I3,11X,7HDIFF  =1BA368500
     1PE13.6,5X,7HQAEO  =1PE13.6,5X,7HQAEI  =1PE13.6,/1X,7HALPHAI=1PE13.BA368600
     26,5X,7HALPHAO=1PE13.6,/17X,95H***** THE ABOVE LIST IS PRINTED BECABA368700
     3USE OUTER RACE CONTROL IS NOT SUFFICIENT FOR THIS BALL *****)   BA368800
 2009 FORMAT(1X,89HTHE ABOVE BALL IS THE MOST HEAVILY LOADED BALL AND THBA368900
     1EREFORE FAILS FOR OUTER RACE CONTROL)                           BA369000
 2010 FORMAT(1X,14HBEARING NUMBER,I2,9X,11HBALL NUMBER,I3,11X,7HDIFF  =1BA369100
     1PE13.6,5X,7HQAEO  =1PE13.6,5X,7HQAEI  =1PE13.6,/1X,7HALPHAI=1PE13.BA369200
     26,5X,7HALPHAO=1PE13.6,/17X,95H***** THE ABOVE LIST IS PRINTED BECABA369300
     3USE INNER RACE CONTROL IS NOT SUFFICIENT FOR THIS BALL *****)   BA369400
 2011 FORMAT(1X,89HTHE ABOVE BALL IS THE MOST HEAVILY LOADED BALL AND THBA369500
     1EREFORE FAILS FOR INNER RACE CONTROL)                           BA369600
 3003 FORMAT(1X,14HBEARING NUMBER,I2,9X,11HBALL NUMBER,I3,11X,7HALPHAO=1BA370800
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         1PE13.6,5X,7HALPHAI=1PE13.5,5X,7HBETA  =1PE13.6,/1X,5OX,7HOMMOOM=1PBA370900
         2E13.5,5X,7HOMROOM=1PE13.6)                                        BA371000
    3004 FORMAT(1X,7HMG     =1PE13.6,5X,7HSX     =1PE13.6,5X,7HSZ     =1PE13.6BA371100
         1,5X,7HFC     =1PE13.6,5X,7HGAMMAI=1PE13.6,/1X,7HGAMMAO=1PE13.6,5X, BA371200
         27HSIGMAO=1PE13.5,5X,7HSIGMAI=1PE13.6)                             BA371300
    3005 FORMAT(1X,7HFRHOO =1PE13.6,5X,7HFRHOI =1PE13.6,5X,7HOSTARO=1PE13.6BA371400
         1,5X,7HOSTARI=1PE13.6,5X,7HKO     =1PE13.6,/1X,7HKI     =1PE13.5)   BA371500
    3007 FORMAT(1X,14HBEARING NUMBER,I2,9X,11HBALL NUMBER,I3,11X,7HV      =1BA372100
         1PE13.6,5X,7HW     =1PE13.5,/51X,7HDELO   =1PE13.6,5X,7HDELI   =1PE13BA372200
         2.5,/51X,7HMG     =1PE13.6,5X,7HALPHAI=1PE13.6,5X,7HALPHAO=1PE13.6)
    3015 FORMAT(1X,7HDELAH =1PE13.5,5X,7HDELRH =1PE13.6,5X,7HTHETAH=1PE13.6BA373900
         1,5X,7HFRH    =1PE13.6,5X,7HMH     =1PE13.6)                       BA374000
         END                                                                BA374100
*FOR,IS INPUT,INPUT
         SUBROUTINE INPUT
         COMMON /LB1/
     $                 ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAT( 4)           BA300900
     1,                ALPHMU( 4)     ,MUO( 4)        ,NUO( 4)              BA301000
     2,                NU1( 4)        ,NU2( 4)        ,D( 4)                BA301100
     4,                DI( 4)         ,DO( 4)         ,E1( 4)               BA301200
     4,                E2( 4)         ,EH( 4)         ,CS( 4)               BA301300
     4,                FS( 4)         ,PH( 4, 4)      ,LH( 4)               BA301400
     6,                KH( 4)         ,VH( 4)         ,FAH( 4)              BA301500
     7,                IH( 4)         ,JH( 4)         ,ZH( 4)               BA301600
     8,                SLH( 4)        ,TH( 4, 4)      ,DELA( 4)             BA301700
     9,                DELR( 4)       ,THETA( 4)      ,OMEAN( 4)            BA301800
     T,                GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 4)            BA301900
     1,                FI( 4)         ,FO( 4)         ,BOBAR( 4)            BA302000
     2,                R( 4)          ,M( 4)          ,NTS
         COMMON /LB2/
     $                 PSI( 4,16)     ,ALPHAO( 4,16) ,ALPHAI( 4,16)         BA302200
     1,                BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)         BA302300
     2,                MG( 4,16)      ,SX( 4,16)     ,SZ( 4,16)             BA302400
     4,                FC( 4,16)      ,GAMMAI( 4,16) ,GAMMAO( 4,16)         BA302500
     4,                SIGMAI( 4,16)  ,SIGMAO( 4,16) ,FRHOO( 4,16)          BA302600
     4,                FRHOI( 4,16)   ,OSTARO( 4,16) ,KO( 4,16)             BA302700
     6,                KI( 4,16)      ,OSTARI( 4,16) ,W( 4,16)              BA302800
     7,                DELO( 4,16)    ,DELI( 4,16)                          BA302900
         COMMON /LB3/
     $                 FTAB(23)       ,ATAB(23)       ,BTAB(23)             BA303000
     1,                DTAB(23)                                             BA303100
         COMMON /LB4/
     $                 DO( 4,16)      ,DI( 4,16)      ,ASTARI( 4,16)        BA303200
     1,                ASTARO( 4,16)  ,AI( 4,16)      ,AO( 4,16)            BA303300
     2,                BSTARI( 4,16)  ,BSTARO( 4,16) ,BI( 4,16)             BA303400
     4,                BO( 4,16)      ,EPSIO( 4,16)  ,EPSII( 4,16)          BA303500
     4,                QAEI( 4,16)    ,QAEO( 4,16)                          BA303600
     7,                W(4,16)        ,SUM( 4,5,4)   ,XI( 4,16)             BA303900
     8,                NPL( 4)        ,NTL( 4)        ,NAH( 4)              BA304000
     9,                AH( 4, 4)      ,VM( 4)         ,DSDOR( 4,16)         BA304100
         COMMON /LB5/
     $                 NO( 4)                                               BA304200
     1,                EIY( 4)                        ,DELAH( 4)            BA304300
     2,                DELRH( 4)      ,THETAH( 4)     ,FRH( 4)              BA304400
     4,                MH( 4)         ,RXP( 4)        ,EP( 4)               BA304500
     4,                UB( 4)         ,JR( 4)         ,J( 4)                BA304600
     4,                IMO( 4)        ,JMO( 4)        ,IMI( 4)              BA304700
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     6,             JMI( 4)       ,QMAXI( 4)     ,QMAXO( 4)          BA304800
     7,             ICHANG( 4)    ,SI( 4,16)     ,SO( 4,16)          BA304900
     8,             HO( 4)        ,IRC( 4)       ,HVH(4)             BA305000
      COMMON /LB36/
     $              STAB(4)       ,CTAB(4)       ,AETAT3(4)
      COMMON /LB37/
     $              LTYPE( 4)     ,FoETA( 4)     ,ICO(4)             BA305300
     $,             HF( 4)        ,HL( 4)        ,HS( 4)             BA305400
     $,             HTOTAL( 4)                                       BA305500
     $,             MV( 4)        ,ML( 4)        ,MJ(4)
     1,             MS( 4,15)     ,NS( 4,15)     ,LAMBDA( 4)
      COMMON /LB6/ ICR,LPT,SP,SQ,PI
      COMMON /SLOAD/
     1              SELX( 5)      ,SELY( 5)      ,SELALP( 5)
      DIMENSION DENSL(4),DENSB(4)
      REAL MV,ML,MJ,MS,NS,LAMBDA,NM,MH,NO
      REAL NUO,NUD,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                     BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
  100 READ(ICR,1000) INSTR                                           BA308800
      IF(INSTR.EQ.0) GO TO 200                                       BA308900
      GO TO(101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,BA309000
     A116,117,118,119,120,121,122,123,124,125,126            ),INSTR BA309100
  101 READ(ICR,1001)(D(I),I=1,NTS)                                   BA309200
C D      = BALL DIAMETER                                             BA309300
      GO TO 100                                                      BA309400
  102 READ(ICR,1001)(DI(I),I=1,NTS)                                  BA309500
C DI     = INNER RACEWAY DIAMETER                                    BA309600
      GO TO 100                                                      BA309700
  103 READ(ICR,1001)(DO(I),I=1,NTS)                                  BA309800
C DO     = OUTER RACEWAY DIAMETER                                    BA309900
      GO TO 100                                                      BA310000
  104 READ(ICR,1001)(E1(I),I=1,NTS)                                  BA310100
C E1     = MODULUS OF ELASTICITY OF THE BALL                         BA310200
      GO TO 100                                                      BA310300
  105 READ(ICR,1001)(E2(I),I=1,NTS)                                  BA310400
C E2     = MODULUS OF ELASTICITY OF THE BEARING                      BA310500
      GO TO 100                                                      BA310600
  106 READ(ICR,1001)(EH(I),I=1,NTS)                                  BA310700
C EH     = MODULUS OF ELASTICITY OF SHAFT H                          BA310800
      GO TO 100                                                      BA310900
  107 READ(ICR,1001)(ALPHA(I),I=1,NTS)                               BA311000
C ALPHA  = INITIAL CONTACT ANGLE PRIOR TO LOADING (DEGREES)          BA311100
      GO TO 100                                                      BA311200
  108 READ(ICR,1001)(ALPHAT(I),I=1,NTS)                              BA311500
C ALPHAT = TEMPERATURE COEFFICIENT OF VISCOSITY                      BA311700
      GO TO 100                                                      BA311800
  109 READ(ICR,1001)(ALPHMJ(I),I=1,NTS)                              BA311900
C ALPHMJ = PRESSURE VISCOSITY COMPONENT                              BA312000
      GO TO 100                                                      BA312100
  110 READ(ICR,1001)(DENSL(I),I=1,NTS)
C DENSL  = DENSITY OF THE LUBRICANT T-AMBIENT (LB/FT**3)
      GO TO 100                                                      BA312400
  111 READ(ICR,1001)(NUO(I),I=1,NTS)                                 BA312500
C NUO    = KINEMATIC VISCOSITY OF THE LUBRICANT AT T-AMBIENT
C            CENTISTOKES (FT**2/SEC)
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      GO TO 100                                                         BA312700
  112 READ(ICR,1001)(NU1(I),I=1,NTS)                                    BA312800
C NU1     = POISSONS RATIO FOR THE BALL                                 BA312900
      GO TO 100                                                         BA313000
  113 READ(ICR,1001)(NU2(I),I=1,NTS)                                    BA313100
C NU2     = POISSONS RATIO FOR THE RACEWAY                              BA313200
      GO TO 100                                                         BA313300
  114 READ(ICR,1001)(CS(I),I=1,NTS)                                     BA313400
C CS      = BASIC STATIC CAPACITY                                       BA313500
      GO TO 100                                                         BA313600
  115 READ(ICR,1000) (NPL(I),I=1,NTS)                                   BA314000
      DO 1150 I=1,NTS                                                   BA314100
      J=NPL(I)                                                          BA314200
 1150 READ(ICR,1001) (PH(I,K),K=1,J)                                    BA314300
C PH      = CONCENTRATED LOAD TO THE SHAFT                              BA314400
      GO TO 100                                                         BA314500
  116 READ(ICR,1001)(IH(I),I=1,NTS)                                     BA314600
C IH      = MOMENT OF INERTIA FOR THE SHAFT                             BA314700
      GO TO 100                                                         BA314800
  117 READ(ICR,1001)(DENSB(I),I=1,NTS)
C DENSB   = DENSITY OF THE BALLS (LB/FT**3)
      GO TO 100                                                         BA315100
  118 READ(ICR,1001)(LH(I),I=1,NTS)                                     BA315200
C LH      = SPAN OF SHAFT # (INCHES)                                    BA315300
      GO TO 100                                                         BA315400
  119 READ(ICR,1001)(KH(I),I=1,NTS)                                     BA315500
C KH      = THERMAL CONDUCTIVITY OF THE LUBRICANT                       BA315600
      GO TO 100                                                         BA315700
  120 READ(ICR,1001)(NH(I),I=1,NTS)                                     BA315800
C NH      = RPM OF ROTATING RACEWAY                                     BA315900
      GO TO 100                                                         BA316000
  121 READ(ICR,1001)(FAH(I),I=1,NTS)                                    BA316100
C FAH     = AXIAL REACTION FORCE (THRUST LOAD) OF BEARINGS
      GO TO 100                                                         BA316300
  122 READ(ICR,1000) (NTL(I),I=1,NTS)                                   BA316400
      DO 1220 I=1,NTS                                                   BA316500
      J=NTL(I)                                                          BA316600
 1220 READ(ICR,1001) (TH(I,K),K=1,J)                                    BA316700
C TH      = APPLIED TORQUE TO SHAFT #                                   BA316800
      GO TO 100                                                         BA316900
  123 READ(ICR,1000)(ZH(I),I=1,NTS)                                     BA317000
C ZH      = NUMBER OF BALLS IN BEARING #                                BA317100
      GO TO 100                                                         BA317200
  124 READ(ICR,1000) (LTYPE(I),I=1,NTS)                                 BA317300
C LTYPE   = TYPE OF LUBRICANT, =1 FOR MIST, =2 FOR GREASE, =4 FOR JET   BA317400
C           0 FOR NON LUBRICANT
      READ(ICR,1001) (MU(I),I=1,NTS)                                    BA317500
C MU      = COEFFICIENT FO FRICTION FOR EACH BEARING                    BA317600
      GO TO 100                                                         BA317700
  125 READ(ICR,1000)(IRRC(I),I=1,NTS)                                   BA317800
C IRRC    = ROTATING RACEWAY CONTROL, = 1 FOR INNER, = 0 FOR OUTER ROTATEBA317900
      GO TO 100                                                         BA318000
  126 READ(ICR,1000)(NAH(I),I=1,NTS)                                    BA318400
      DO 1260 I=1,NTS                                                   BA318500
      J=NAH(I)                                                          BA318600
 1260 READ(ICR,1001) (AH(I,K),K=1,J)                                    BA318700
      GO TO 100                                                         BA318800
```

```
  230 CONTINUE                                                                    BA318900
      DO 150 I=1,NTS
C M       = MASS OF EACH BALL
      M(I)=DENSB(I)*(1./6.)*PI*D(I)**3/1728.
C JH      = MASS MOMENT OF INERTIA FOR EACH BALL
      JH(I)=M(I)*C.4*(D(I)/2.)**2
      MJD(I)=NJD(I)*DENSL(I)
      CALL LAGRAN(ALPHA(I),SELALP,SELX,5,2,XS,NERR)
      IF((NERR.EQ.1).OR.(NERR.EQ.2)) WRITE(LPT,2041) ALPHA(I)
      CALL LAGRAN(ALPHA(I),SELALP,SELY,5,2,YS,NERR)
      IF((NERR.EQ.1).OR.(NERR.EQ.2)) WRITE(LPT,2041) ALPHA(I)
  150 FS(I)=XS*PH(I)+YS*FAH(I)
      NDC=0                                                                       BA319000
      DO 201 I=1,NTS                                                              BA319100
      OMEGA(I)=(NH(I)*2.*PI)/60.                                                  BA322900
      ALPHA(I)=ALPHA(I)/57.2957795                                                BA323000
      NB=ZH(I)                                                                    BA319200
      DO 201 J=1,NB                                                               BA319300
      PSI(I,J)=((2.*PI)/FLOAT(ZH(I)))*(FLOAT(J-1))                                BA319400
  201 CONTINUE                                                                    BA319500
      WRITE(LPT,2000)                                                             BA319600
      WRITE(LPT,2001)                                                             BA319700
      DO 210 I=1,NTS                                                              BA319800
      WRITE(LPT,2002)I,D(I),DI(I),DO(I),E1(I),E2(I),EH(I),ALPHA(I),DENSBBA319900
     1(I) ,ALPHAT(I),ALPHMJ(I),MJD(I),NUD(I),NU1(I),NU2(I),CS(I),FS(I), BA320000
     2IH(I),JH(I),LH(I),KH(I),NH(I),FAH(I),ZH(I),IRRC(I),M(I),MJ(I)
     3,DENSL(I)
      J=NPL(I)                                                                    BA320200
      WRITE(LPT,2030)(PH(I,K),K=1,J)                                              BA320300
      J=NTL(I)                                                                    BA320400
      WRITE(LPT,2031)(TH(I,K),K=1,J)                                              BA320500
      J=NAH(I)                                                                    BA320600
      WRITE(LPT,2032)(AH(I,K),K=1,J)                                              BA320700
      NB=ZH(I)                                                                    BA320800
      WRITE(LPT,2003)(PSI(I,J),J=1,NB)                                            BA320900
  210 CONTINUE                                                                    BA321000
 1000 FORMAT(8I10)
 1001 FORMAT(8E10.0)                                                              BA366800
 2000 FORMAT(1H1)                                                                 BA366900
 2001 FORMAT(30X,66HROLLER BEARING ANALYSIS PROGRAM TO DETERMINE TOTAL HBA367000
     1EAT GENERATION,//,1X,16HINPUT PARAMETERS)                                   BA367100
 2002 FORMAT(1X,14HBEARING NUMBER,I2,/1X,7HD      =1PE13.6,5X,7HDI     =1PBA367200
     1E13.6,5X,7HDO     =1PE13.6,5X,7HE1     =1PE13.6,5X,7HE2     =1PE13.6,BA367300
     2/1X,7HEH     =1PE13.6,5X,7HALPHA =1PE13.6,5X,7HDENSB =1PE13.6,5X,7HBA367400
     3ALPHAT=1PE13.6,5X,7HALPHMJ=1PE13.6,/1X,7HMUD    =1PE13.6,5X,7HNUD   BA367500
     4 =1PE13.6,5X,7HNU1    =1PE13.6,5X,7HNU2    =1PE13.6,5X,7HCS     =1PE1BA367600
     53.6,/1X,7HFS     =1PE13.6,5X,7HIH     =1PE13.6,5X,7HJH     =1PE13.6,5BA367700
     6X,7HLH     =1PE13.6,5X,7HKH     =1PE13.6,/1X,7HNH     =1PE13.6,5X,7HFBA367800
     7AH    =1PE13.6,5X,7HZH     =I4,14X,7HIRRC   =I4,14X,7HMASS   =1PE13.6,
     8/1X,7HMU     =1PE13.6,5X,7HDENSL =1PE13.6)
 2003 FORMAT(1X,7HPSI    =1PE13.5)
 2030 FORMAT(1X,7HPH     =1PE13.5)
 2031 FORMAT(1X,7HTH     =1PE13.5)
 2032 FORMAT(1X,7HAH     =1PE13.5)
 2041 FORMAT(1X,7HALPHA =1PE13.5,23H IS OUTSIDE TABLE RANGE)
      RETURN
      END
```

```
@FOR,IS INIT,INIT
      SUBROUTINE INIT
      COMMON /LB1/
     $          ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAT( 4)        BA300900
     1,         ALPHMU( 4)     ,MUO( 4)        ,MUD( 4)           BA301000
     2,         NUI( 4)        ,NU2( 4)        ,D( 4)             BA301100
     4,         DI( 4)         ,DO( 4)         ,E1( 4)            BA301200
     4,         E2( 4)         ,EH( 4)         ,CS( 4)            BA301300
     4,         FS( 4)         ,PH( 4, 4)      ,LH( 4)            BA301400
     6,         KH( 4)         ,VH( 4)         ,FAH( 4)           BA301500
     7,         IH( 4)         ,JH( 4)         ,ZH( 4)            BA301500
     8,         SLH( 4)        ,TH( 4, 4)      ,DELA( 4)          BA301700
     9,         DELR( 4)       ,THETA( 4)      ,OMEAN( 4)         BA301800
     T,         GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 4)         BA301900
     1,         FI( 4)         ,FO( 4)         ,BOBAR( 4)         BA302000
     2,         R( 4)          ,M( 4)          ,NTS
      COMMON /LB2/
     $          PSI( 4,16)     ,ALPHAO( 4,16) ,ALPHAI( 4,16)      BA302200
     1,         BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)      BA302300
     2,         MG( 4,15)      ,SX( 4,16)     ,SZ( 4,15)          BA302400
     4,         FC( 4,15)      ,GAMMAI( 4,15) ,GAMMAO( 4,16)      BA302500
     4,         SIGMAI( 4,16)  ,SIGMAO( 4,15) ,FRHOO( 4,16)       BA302600
     4,         FRHOI( 4,16)   ,DSTARO( 4,16) ,KO( 4,15)          BA302700
     6,         KI( 4,15)      ,DSTARI( 4,16) ,W( 4,15)           BA302800
     7,         DELO( 4,16)    ,DELI( 4,16)                       BA302900
      COMMON /LB3/
     $          FTAB(23)       ,ATAB(23)       ,BTAB(23)          BA303000
     1,         DTAB(23)                                          BA303100
      COMMON /LB4/
     $          DO( 4,15)      ,DI( 4,15)     ,ASTARI( 4,16)      BA303200
     1,         ASTARO( 4,16)  ,AI( 4,15)     ,AO( 4,16)          BA303300
     2,         BSTARI( 4,16)  ,BSTARO( 4,16) ,BI( 4,16)          BA303400
     4,         BO( 4,15)      ,EPSIO( 4,16)  ,EPSII( 4,16)       BA303500
     4,         QAEI( 4,16)    ,QAEO( 4,15)                       BA303600
     7,         W(4,16)        ,SUM( 4,5,4)   ,KI( 4,16)          BA303900
     8,         NPL( 4)        ,NTL( 4)       ,NAH( 4)            BA304000
     9,         AH( 4, 4)      ,NM( 4)        ,OSOOR( 4,16)       BA304100
      COMMON /LB5/
     $          NO( 4)                                            BA304200
     1,         EIY( 4)                        ,DELAH( 4)         BA304300
     2,         DELRH( 4)      ,THETAH( 4)     ,FRH( 4)           BA304400
     4,         MH( 4)         ,RXP( 4)        ,EP( 4)            BA304500
     4,         UB( 4)         ,UR( 4)         ,J( 4)             BA304600
     4,         IMO( 4)        ,JMO( 4)        ,IMI( 4)           BA304700
     6,         JMI( 4)        ,QMAXI( 4)      ,QMAXO( 4)         BA304800
     7,         ICHANG( 4)     ,SI( 4,16)      ,SO( 4,16)         BA304900
     8,         HO( 4)         ,IRC( 4)        ,HVH(4)            BA305000
      COMMON /LB6/
     $          STAB(4)        ,CTAB(4)        ,AETAT3(4)
      COMMON /LB7/
     $          LTYPE( 4)      ,FBETA( 4)      ,ICO(4)            BA305300
     $,         HF( 4)         ,HL( 4)         ,HS( 4)            BA305400
     $,         HTOTAL( 4)                                        BA305500
     $,         MV( 4)         ,ML( 4)         ,MU(4)
     1,         MS( 4,16)      ,NS( 4,16)      ,LAMBDA( 4)
      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      REAL MV,ML,MJ,MS,NS,LAMBDA,NM,MH,NO
```

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      REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                        BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
      DO 3100 I=1,NTS                                                   BA321200
      IF(IRRC(I).EQ.1) LAMBDA(I)=0.                                     BA331400
      IF(IRRC(I).EQ.0) LAMBDA(I)=1.                                     BA331500
      ICO(I)=ICHANG(I)                                                  BA321300
      IF(ICHANG(I).EQ.1)IRC(I)=0                                        BA321400
      IF(IRC(I).EQ.1)WRITE(LPT,2004) I                                  BA321500
      IF(IRC(I).EQ.0) WRITE(LPT,2005) I                                 BA321500
 3100 CONTINUE                                                          BA321700
      DO 3110 I=1,NTS                                                   BA321800
C INITIALIZE VALUES FOR DELA, DELR, AND THETA                           BA322700
      DMEAN(I)=(DO(I)+DI(I))/2.                                         BA324900
      GAMMAP(I)=D(I)/DMEAN(I)                                           BA325000
      WRITE(LPT,3002)I,DMEAN(I),GAMMAP(I)                               BA325100
      FI(I)=DI(I)/(2.*D(I))                                             BA323700
      FO(I)=DO(I)/(2.*D(I))                                             BA323800
      DELA(I)=(1.58E-5)*((FAH(I)/(FLOAT(ZH(I))*SIN(ALPHA(I))))**(2./3.))BA323900
     1/(D(I)**(1./3.)*SIN(ALPHA(I)))                                    BA324000
      DELR(I)=(8.71E-7)*((2.5*(PH(I,1)+PH(I+1,1)))/(ZH(I)*COS(ALPHA(I)))BA324100
     1)**0.9/(LH(I)**0.8*COS(ALPHA(I)))                                 BA324200
      THETA(I)=(2.*DELA(I))/DO(I)                                       BA324300
      BDBAR(I)=(FO(I)+FI(I)-1.)*D(I)                                    BA324400
      PD=DO(I)-DI(I)-2.*D(I)
      COSAS=1.-(PD/(2.*BDBAR(I)))
      SINAS=SQRT(1.-COSAS**2)
      ALPHAS(I)=ABS(ATAN(SINAS/COSAS))
      R(I)=0.5*DMEAN(I)+(FI(I)-.5)*D(I)*COS(ALPHAS(I))                  BA324500
      WRITE(LPT,3001)I,DELA(I),DELR(I),THETA(I),OMEGA(I)                BA324600
      DELAH(I)=DELA(I)
      DELRH(I)=DELR(I)
      THETAH(I)=THETA(I)
      MH(I)=M(I)
      FRH(I)=FAH(I)                                                     BA321900
      NB=ZH(I)                                                          BA322000
      DO 3110 J=1,NB                                                    BA322100
      V(I,J)=(FO(I)-0.5)*D(I)
      W(I,J)=(FI(I)-0.5)*D(I)
      DELO(I,J)=(4.36E-7)*FS(I)
      DELI(I,J)=(4.36E-7)*FS(I)
      MG(I,J)=JH(I)*OMEGA(I)**2
      CAI=(BDBAR(I)-V(I,J))/((FI(I)-0.5)*D(I)+DELI(I,J))
      CAO=V(I,J)/((FO(I)-0.5)*D(I)+DELO(I,J))
      SAI=SQRT(1.-CAI**2)
      SAO=SQRT(1.-CAO**2)
      ALPHAI(I,J)=ATAN(SAI/CAI)
      ALPHAO(I,J)=ATAN(SAO/CAO)
      FC(I,J)=0.001295*M(I)*DMEAN(I)*OMEGA(I)**2
 3110 CONTINUE                                                          BA322600
 2004 FORMAT(1X,48HINNER RACEWAY IS CONTROLLED FOR BEARING NUMBER =I4)  BA368100
 2005 FORMAT(1X,48HOUTER RACEWAY IS CONTROLLED FOR BEARING NUMBER =I4)  BA368200
 3001 FORMAT(1X,14HBEARING NUMBER,I2,9X,7HDELA  =1PE13.5,5X,7HDELR  =1PEBA370400
     113.6,5X,7HTHETA =1PE13.6,5X,7HOMEGA =1PE13.6)
 3002 FORMAT(1X,14HBEARING NUMBER,I2,9X,7HDMEAN =1PE13.5,5X,7HGAMMAP=1PEBA370500
     113.6)                                                             BA370700
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      RETURN
      END
@FOR,IS BLK4,BLK4
      SUBROUTINE BLK4
      COMMON /LB1/
     $               ALPHAS( 4)      ,ALPHA( 4)      ,ALPHAT( 4)           BA300900
     1,              ALPHMU( 4)      ,NU0( 4)        ,NU3( 4)              BA301000
     2,              NU1( 4)         ,NU2( 4)        ,D( 4)                BA301100
     4,              DI( 4)          ,DO( 4)         ,E1( 4)               BA301200
     4,              E2( 4)          ,EH( 4)         ,CS( 4)               BA301300
     4,              FS( 4)          ,PH( 4, 4)      ,LH( 4)               BA301400
     6,              KH( 4)          ,NH( 4)         ,FAH( 4)              BA301500
     7,              IH( 4)          ,JH( 4)         ,ZH( 4)               BA301500
     8,              SLH( 4)         ,TH( 4, 4)      ,DELA( 4)             BA301700
     9,              DELR( 4)        ,THETA( 4)      ,DMEAN( 4)            BA301900
     T,              GAMMAP( 4)      ,IRRC( 4)       ,DMESA( 4)            BA301900
     1,              FI( 4)          ,FO( 4)         ,BDBAR( 4)            BA302000
     2,              R( 4)           ,M( 4)          ,NTS
      COMMON /LB2/
     $               PSI( 4,16)      ,ALPHAO( 4,16) ,ALPHAI( 4,16)         BA302200
     1,              BETA( 4,16)     ,OMMOOM( 4,16) ,OMROOM( 4,16)         BA302300
     2,              MS( 4,15)       ,SX( 4,15)     ,SZ( 4,16)             BA302400
     4,              FC( 4,15)       ,GAMMAI( 4,16) ,GAMMAO( 4,16)         BA302500
     4,              SIGMAI( 4,16)   ,SIGMAO( 4,15) ,FRHOO( 4,16)          BA302600
     4,              FRHOI( 4,16)    ,DSTARO( 4,16) ,KO( 4,15)             BA302700
     5,              KI( 4,15)       ,DSTARI( 4,15) ,V( 4,15)              BA302800
     7,              DELO( 4,16)     ,DELI( 4,16)                          BA302900
      COMMON /LB3/
     $               FTAB(23)        ,ATAB(23)      ,BTAB(23)              BA303000
     1,              DTAB(23)                                              BA303100
      COMMON /LB4/
     $               DO( 4,15)       ,DI( 4,16)     ,ASTARI( 4,16)         BA303200
     1,              ASTARO( 4,16)   ,AI( 4,16)     ,AO( 4,16)             BA303300
     2,              BSTARI( 4,16)   ,BSTARO( 4,16) ,BI( 4,16)             BA303400
     4,              BO( 4,15)       ,EPSIO( 4,16)  ,EPSII( 4,16)          BA303500
     4,              DAEI( 4,16)     ,DAEO( 4,16)                          BA303600
     7,              W(4,16)         ,SUM( 4,5,4)   ,KI( 4,16)             BA303900
     8,              NPL( 4)         ,NTL( 4)       ,NAH( 4)               BA304000
     9,              AH( 4, 4)       ,NM( 4)        ,DSOOR( 4,16)          BA304100
      COMMON /LB5/
     $               NO( 4)                                                BA304200
     1,              EIY( 4)                        ,DELAH( 4)             BA304300
     2,              DELRH( 4)       ,THETAH( 4)    ,FRH( 4)               BA304400
     4,              MH( 4)          ,RXP( 4)       ,EP( 4)                BA304500
     4,              JB( 4)          ,JR( 4)        ,J( 4)                 BA304600
     4,              IMO( 4)         ,JMO( 4)       ,IMI( 4)               BA304700
     6,              JMI( 4)         ,DMAXI( 4)     ,DMAXO( 4)             BA304800
     7,              ICHANG( 4)      ,SI( 4,16)     ,SO( 4,15)             BA304900
     8,              HO( 4)          ,IRC( 4)       ,NVH(4)                BA305000
      COMMON /LB6/
     $               STAB(4)         ,CTAB(4)       ,AETAT3(4)
      COMMON /LB7/
     $               LTYPE( 4)       ,FBETA( 4)     ,ICO(4)                BA305300
     $,              HF( 4)          ,HL( 4)        ,HS( 4)                BA305400
     $,              HTOTAL( 4)                                            BA305500
     $,              MV( 4)          ,ML( 4)        ,MJ(4)
     1,              MS( 4,15)       ,NS( 4,16)     ,LAMBDA( 4)
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      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      COMMON /NLIN/
     $               X(20)          ,F(20)          ,AJINV(20,20)
     1,              WORK(950)      ,JC(20)         ,ISYS
     S,              N              ,I              ,J
      DOUBLE PRECISION X,F,AJINV,WORK
      REAL MV,ML,MJ,MS,NS,LAMBDA,N4,MH,NO
      REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                        BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
      SX(I,J)=BOBAR(I)*SIN(ALPHA(I))+DELA(I)+THETA(I)*R(I)*COS(PSI(I,J))BA328800
      SZ(I,J)=BOBAR(I)*COS (ALPHA(I))+DELR(I)*COS(PSI(I,J))             BA328900
      RETURN
      END
@FOR,IS BLK5,BLK5
      SUBROUTINE BLK5
      COMMON /LB1/
     $               ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAT( 4)         BA300900
     1,              ALPHMU( 4)     ,MUO( 4)        ,NUO( 4)            BA301000
     2,              NU1( 4)        ,NU2( 4)        ,D( 4)              BA301100
     4,              DI( 4)         ,DO( 4)         ,E1( 4)             BA301200
     4,              E2( 4)         ,EH( 4)         ,ES( 4)             BA301300
     4,              FS( 4)         ,PH( 8, 4)      ,LH( 4)             BA301400
     6,              KH( 4)         ,NH( 4)         ,FAH( 4)            BA301500
     7,              IH( 4)         ,JH( 4)         ,ZH( 4)             BA301500
     8,              SLH( 4)        ,TH( 4, 4)      ,DELA( 4)           BA301700
     9,              DELR( 4)       ,THETA( 4)      ,OMEAN( 4)          BA301800
     T,              GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 4)          BA301900
     1,              FI( 4)         ,FO( 4)         ,BOBAR( 4)          BA302000
     2,              R( 4)          ,M( 4)          ,NTS
      COMMON /LB2/
     $               PSI( 4,16)     ,ALPHAO( 4,16) ,ALPHAI( 4,16)       BA302200
     1,              BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)       BA302300
     2,              MG( 4,15)      ,SX( 4,16)     ,SZ( 4,16)           BA302400
     4,              FC( 4,15)      ,GAMMAI( 4,15) ,GAMMAO( 4,16)       BA302500
     4,              SIGMAI( 4,16)  ,SIGMAO( 4,16) ,FRHOO( 4,16)        BA302600
     4,              FRHOI( 4,16)   ,OSTARO( 4,15) ,KO( 4,16)           BA302700
     6,              KI( 4,15)      ,OSTARI( 4,15) ,V( 4,16)            BA302800
     7,              DELO( 4,16)    ,DELI( 4,16)                        BA302900
      COMMON /LB3/
     $               FTAB(23)       ,ATAB(23)      ,BTAB(23)            BA303000
     1,              DTAB(23)                                           BA303100
      COMMON /LB4/
     $               QO( 4,15)      ,QI( 4,16)     ,ASTARI( 4,16)       BA303200
     1,              ASTARO( 4,16)  ,AI( 4,16)     ,AO( 4,15)           BA303300
     2,              BSTARI( 4,16)  ,BSTARO( 4,16) ,BI( 4,15)           BA303400
     4,              BO( 4,15)      ,EPSIO( 4,16)  ,EPSII( 4,16)        BA303500
     4,              DAEI( 4,16)    ,DAEO( 4,16)                        BA303600
     7,              W(4,16)        ,SUM( 4,5,4)   ,XI( 4,16)           BA303900
     8,              NPL( 4)        ,NTL( 4)       ,NAH( 4)             BA304000
     9,              AH( 4, 4)      ,NM( 4)        ,DSQDR( 4,16)        BA304100
      COMMON /LB5/
     $               NU( 4)                                             BA304200
     1,              EIY( 4)                       ,DELAH( 4)           BA304300
     2,              DELRH( 4)      ,THETAH( 4)    ,FRH( 4)             BA304400
     4,              MH( 4)         ,RXP( 4)       ,EP( 4)              BA304500
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     4,        JB( 4)        ,JR( 4)        ,J( 4)                BA304600
     4,        IMO( 4)       ,JMO( 4)       ,IMI( 4)              BA304700
     6,        JMI( 4)       ,DMAXI( 4)     ,DMAXO( 4)            BA304800
     7,        ICHANG( 4)    ,SI( 4,16)     ,SO( 4,15)            BA304900
     6,        HO( 4)        ,IRC( 4)       ,HVH(4)               BA305000
     COMMON /L36/
     $         STAB(4)       ,CTAB(4)       ,AETAT3(4)
     COMMON /L37/
     $         LTYPE( 4)     ,FBETA( 4)     ,ICO(4)               BA305300
     $,        HF( 4)        ,HL( 4)        ,HS( 4)               BA305400
     $,        HTOTAL( 4)                                         BA305500
     $,        MV( 4)        ,ML( 4)        ,MJ(4)
     1,        MS( 4,15)     ,NS( 4,16)     ,LAMBDA( 4)
     COMMON /L38/ ICR,LPT,SP,SQ,PI
     REAL MV,ML,MJ,MS,NS,LAMBDA,N4,MH,NO
     REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
     INTEGER ZH                                                   BA305600
     TAN(Q)=SIN(Q)/COS(Q)
     COT(Q)=COS(Q)/SIN(Q)
C CALCULATE DELA,DELR, AND THETA FOR EACH BEARING                  BA333100
     DO 501 I=1,NTS                                               BA333200
     NB=ZH(I)                                                     BA333300
     DO 501 J=1,NB                                                BA333400
 501 XI(I,J)=(FI(I)-0.5)*D(I)+DELI(I,J)                           BA333500
     DO 550 I=1,NTS                                               BA333600
     DO 505 J=1,5                                                 BA333700
     DO 505 K=1,4                                                 BA333800
 505 SJM(I,J,K)=0.                                                BA333900
     NB=ZH(I)                                                     BA334000
     DO 530 J=1,NB                                                BA334100
     SDI=1.
     IF(DELI(I,J).LT.0.) SDI=-1.
     DELI15=SDI*ABS(DELI(I,J))**1.5
     SJM(I,1,1)=SJM(I,1,1)+(KI(I,J)*DELI15)/XI(I,J)
     SJM(I,1,2)=SJM(I,1,2)+((2.*(1.-LAMBDA(I))*MG(I,J))/D(I))*COS(PSI(IBA334300
    1,J))/XI(I,J)                                                 BA334400
     SJM(I,1,3)=SJM(I,1,3)+(KI(I,J)*DELI15*R(I)*COS(PSI(I,J)))/XI(I,J)
     SJM(I,1,4)=SJM(I,1,4)+(KI(I,J)*(BDBAR(I)*SIN(ALPHA(I))-W(I,J))*DELBA334700
    1I15)/XI(I,J)-((2.*(1.-LAMBDA(I))*MG(I,J))/D(I))*(BDBAR(I)*
    2COS(ALPHA(I))-V(I,J))/XI(I,J)                                BA334900
     WRITE(LPT,3010)I,SUM(I,1,1),SJM(I,1,2),SJM(I,1,3),SJM(I,1,4) BA335000
     SJM(I,2,1)=SJM(I,2,1)+((2.*(1.-LAMBDA(I))*MG(I,J))/D(I))/XI(I,J) BA335100
     SJM(I,2,2)=SJM(I,2,2)+(KI(I,J)*DELI15*COS(PSI(I,J)))/XI(I,J)
     SJM(I,2,3)=SJM(I,2,3)+((2.*(1.-LAMBDA(I))*MG(I,J))/D(I))*R(I)*COS(BA335400
    1PSI(I,J))/XI(I,J)                                            BA335500
     SJM(I,2,4)=SJM(I,2,4)+(KI(I,J)*(BDBAR(I)*COS(ALPHA(I))-V(I,J))*DELBA335600
    1I15)/XI(I,J)+((2.*(1.-LAMBDA(I))*MG(I,J))/D(I))*(BDBAR(I)*
    2SIN(ALPHA(I))-W(I,J))/XI(I,J)                                BA335800
     WRITE(LPT,3011)I,SJM(I,2,1),SJM(I,2,2),SJM(I,2,3),SJM(I,2,4) BA335900
     SJM(I,3,1)=(R(I)*KI(I,J)*DELI15*COS(PSI(I,J)))/XI(I,J)+SJM(I,3,1)
     SUM(I,3,2)=((2.*(1.-LAMBDA(I))*MG(I,J)/D(I))*R(I)*(COS(PSI(I,J)))*BA336200
    1*2)/XI(I,J)+SUM(I,3,2)                                       BA336300
     SJM(I,3,3)=SJM(I,3,3)+(KI(I,J)*DELI(I,J)*R(I)**2*(COS(PSI(I,J)))**BA336400
    12)/ XI(I,J)                                                  BA336500
     SJM(I,3,4)=SJM(I,3,4)+(((KI(I,J)*(BDBAR(I)*SIN(ALPHA(I))-W(I,J))* BA336600
    1DELI15-(2.*(1.-LAMBDA(I))*MG(I,J)/D(I))*(BDBAR(I)*COS(ALPHA(I
    2))-V(I,J)))*R(I))/XI(I,J)+2.*(1.-LAMBDA(I))*FI(I)*MG(I,J))*COS(PSI BA336700
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     3(I,J))                                                            BA337000
      WRITE(LPT,3012)I,SUM(I,3,1),SUM(I,3,2),SUM(I,3,3),SUM(I,3,4)     BA337100
  530 CONTINUE                                                          BA337200
      IF(I.EQ.1)GO TO 541                                               BA337300
      J=NPL(I-1)                                                        BA337400
      DO 540 K=1,J                                                      BA337500
  540 SUM(I,4,1)=SUM(I,4,1)+PH(I-1,K)*AH(I-1,K)**2*(3.*LH(I-1)-2.*AH(I-1BA337600
     1,K))                                                              BA337700
      SUM(I,4,1)=(1./LH(I-1)**3)*SUM(I,4,1)
  541 CONTINUE                                                          BA337800
      J=NPL(I)                                                          BA337900
      DO 542 K=1,J                                                      BA338000
  542 SUM(I,4,2)=SUM(I,4,2)+PH(I,K)*(LH(I)-AH(I,K))**2*(LH(I)+2.*AH(I,K)BA338100
     1)                                                                 BA338200
      SUM(I,4,2)=(1./LH(I)**3)*SUM(I,4,2)
      IF(I.EQ.1) GO TO 544                                              BA338300
      J=NTL(I-1)                                                        BA338400
      DO 543 K=1,J                                                      BA338500
  543 SUM(I,4,3)=SUM(I,4,3)+TH(I-1,K)*AH(I-1,K)*(LH(I-1)-AH(I-1,K))     BA338600
      SUM(I,4,3)=(6./LH(I-1)**3)*SUM(I,4,3)
  544 CONTINUE                                                          BA338700
      J=NTL(I)                                                          BA338800
      DO 545 K=1,J                                                      BA338900
  545 SUM(I,4,4)=SUM(I,4,4)+TH(I,K)*AH(I,K)*(LH(I)-AH(I,K))             BA339000
      SUM(I,4,4)=(6./LH(I)**3)*SUM(I,4,4)
      WRITE(LPT,3013)I,SUM(I,4,1),SUM(I,4,2),SUM(I,4,3),SUM(I,4,4)      BA339100
      IF(I.EQ.1) GO TO 551                                              BA339200
      J=NPL(I-1)                                                        BA339300
      DO 550 K=1,J                                                      BA339400
  550 SUM(I,5,1)=SUM(I,5,1)+PH(I-1,K)*AH(I-1,K)**2*(LH(I-1)-AH(I-1,K))  BA339500
      SUM(I,5,1)=(1./LH(I-1)**2)*SUM(I,5,1)
  551 CONTINUE                                                          BA339600
      J=NPL(I)                                                          BA339700
      DO 552 K=1,J                                                      BA339800
  552 SUM(I,5,2)=SUM(I,5,2)+PH(I,K)*AH(I,K)*(LH(I)-AH(I,K))**2          BA339900
      SUM(I,5,2)=(1./LH(I)**2)*SUM(I,5,2)
      IF(I.EQ.1) GO TO 554                                              BA340000
      J=NTL(I-1)                                                        BA340100
      DO 553 K=1,J                                                      BA340200
  553 SUM(I,5,3)=SUM(I,5,3)+TH(I-1,K)*AH(I-1,K)*(2.*LH(I-1)-3.*AH(I-1,K)BA340300
     1)                                                                 BA340400
      SUM(I,5,3)=SUM(I,5,3)*(1./LH(I-1)**2)                             BA340500
  554 CONTINUE                                                          BA340600
      J=NTL(I)                                                          BA340700
      DO 555 K=1,J                                                      BA340800
  555 SUM(I,5,4)=SUM(I,5,4)+TH(I,K)*(LH(I)-AH(I,K))*(LH(I)-3.*AH(I,K))  BA340900
      SUM(I,5,4)=SUM(I,5,4)*(1./LH(I)**2)                               BA341000
      WRITE(LPT,3014)I,SUM(I,5,1),SUM(I,5,2),SUM(I,5,3),SUM(I,5,4)      BA341100
  560 CONTINUE                                                          BA341200
 3010 FORMAT(1X,7HBEAR N=I4,14X,7HSUMI11=1PE13.6,5X,7HSUMI12=1PE13.6,5X,BA372900
     17HSUMI13=1PE13.6,5X,7HSUMI14=1PE13.6)                             BA373000
 3011 FORMAT(1X,7HBEAR N=I4,14X,7HSUMI21=1PE13.6,5X,7HSUMI22=1PE13.6,5X,BA373100
     17HSUMI23=1PE13.6,5X,7HSUMI24=1PE13.6)                             BA373200
 3012 FORMAT(1X,7HBEAR N=I4,14X,7HSUMI31=1PE13.6,5X,7HSUMI32=1PE13.6,5X,BA373300
     17HSUMI33=1PE13.6,5X,7HSUMI34=1PE13.6)                             BA373400
 3013 FORMAT(1X,7HBEAR N=I4,14X,7HSUMI41=1PE13.6,5X,7HSUMI42=1PE13.6,5X,BA373500
     17HSUMI43=1PE13.6,5X,7HSUMI44=1PE13.6)                             BA373600
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 3314 FORMAT(1X,7HBEAR N=I4,14X,7HSUMISI=1PE13.6,5X,7HSUMIS2=1PE13.6,5X,BA373700
     17HSUMIS3=1PE13.6,5X,7HSUMIS4=1PE13.6)                           BA373800
      RETURN
      END
@FOR,IS BLK7,BLK7
      SUBROUTINE BLK7
      COMMON /LB1/
     $          ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAT( 4)            BA300900
     1,         ALPHMU( 4)     ,MUO( 4)        ,NUO( 4)               BA301000
     2,         NU1( 4)        ,NU2( 4)        ,D( 4)                 BA301100
     4,         DI( 4)         ,DO( 4)         ,E1( 4)                BA301200
     4,         E2( 4)         ,EH( 4)         ,CS( 4)                BA301300
     4,         FS( 4)         ,PH( 4, 4)      ,LH( 4)                BA301400
     6,         KH( 4)         ,NH( 4)         ,FAH( 4)               BA301500
     7,         IH( 4)         ,JH( 4)         ,ZH( 4)                BA301600
     8,         SLH( 4)        ,TH( 4, 4)      ,DELA( 4)              BA301700
     9,         DELR( 4)       ,THETA( 4)      ,OMEAV( 4)             BA301800
     T,         GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 4)             BA301900
     1,         FI( 4)         ,FO( 4)         ,BOBAR( 4)             BA302000
     2,         R( 4)          ,M( 4)          ,NTS
      COMMON /LB2/
     $          PSI( 4,16)     ,ALPHAO( 4,16)  ,ALPHAI( 4,16)         BA302200
     1,         BETA( 4,16)    ,OMMOOM( 4,16)  ,OMROOM( 4,16)         BA302300
     2,         MG( 4,16)      ,SX( 4,16)      ,SZ( 4,16)             BA302400
     4,         FC( 4,16)      ,GAMMAI( 4,16)  ,GAMMAO( 4,16)         BA302500
     4,         SIGMAI( 4,16)  ,SIGMAO( 4,16)  ,FRHOO( 4,16)          BA302600
     4,         FRHOI( 4,16)   ,DSTARO( 4,16)  ,KO( 4,16)             BA302700
     6,         KI( 4,16)      ,DSTARI( 4,16)  ,W( 4,16)              BA302800
     7,         DELO( 4,16)    ,DELI( 4,16)                           BA302900
      COMMON /LB3/
     $          FTAB(23)       ,ATAB(23)       ,BTAB(23)              BA303000
     1,         DTAB(23)                                              BA303100
      COMMON /LB4/
     $          DO( 4,16)      ,DI( 4,16)      ,ASTARI( 4,16)         BA303200
     1,         ASTARO( 4,16)  ,AI( 4,16)      ,AO( 4,16)             BA303300
     2,         BSTARI( 4,16)  ,BSTARO( 4,16)  ,BI( 4,16)             BA303400
     4,         BO( 4,16)      ,EPSIO( 4,16)   ,EPSII( 4,16)          BA303500
     4,         DAEI( 4,16)    ,DAEO( 4,16)                           BA303600
     7,         W(4,16)        ,SUM( 4,5,4)    ,KI( 4,16)             BA303900
     8,         NPL( 4)        ,NTL( 4)        ,NAH( 4)               BA304000
     9,         AH( 4, 4)      ,NM( 4)         ,DSOOR( 4,16)          BA304100
      COMMON /LB5/
     $          NO( 4)                                                BA304200
     1,         EIY( 4)                        ,DELAH( 4)             BA304300
     2,         DELRH( 4)      ,THETAH( 4)     ,FRH( 4)               BA304400
     4,         MH( 4)         ,RXP( 4)        ,EP( 4)                BA304500
     4,         UB( 4)         ,JR( 4)         ,J( 4)                 BA304600
     4,         IMO( 4)        ,JMO( 4)        ,IMI( 4)               BA304700
     6,         JMI( 4)        ,OMAXI( 4)      ,OMAXO( 4)             BA304800
     7,         ICHANG( 4)     ,SI( 4,16)      ,SO( 4,16)             BA304900
     8,         HO( 4)         ,IRC( 4)        ,HVH(4)                BA305000
      COMMON /LB6/
     $          STAB(4)        ,CTAB(4)        ,AETATB(4)
      COMMON /LB7/
     $          LTYPE( 4)      ,FBETA( 4)      ,ICO(4)                BA305300
     $,         HF( 4)         ,HL( 4)         ,HS( 4)                BA305400
     1,         HTOTAL( 4)                                            BA305500
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     $,              MV( 4)         ,ML( 4)         ,MU(4)
     1,              MS( 4,16)      ,NS( 4,16)      ,LAMBDA( 4)
      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      REAL MV,ML,MJ,MS,NS,LAMBDA,MM,MH,MO
      REAL MUD,NUD,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                        BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
      DO 705 I=1,NTS                                                    BA344700
      QMAXI(I)=0.                                                       BA344800
  705 QMAXO(I)=0.                                                       BA344900
      DO 750 I=1,NTS                                                    BA345000
      NB=ZH(I)                                                          BA345100
      DO 750 J=1,NB                                                     BA345200
C CALCULATE NORMAL LOAD                                                  BA345900
      SDI=1.
      SDO=1.
      IF(DELO(I,J).LT.0.)SDO=-1.
      IF(DELI(I,J).LT.0.) SDI=-1.
      DELO15=SDO*ABS(DELO(I,J))**1.5
      DELI15=SDI*ABS(DELI(I,J))**1.5
      QI(I,J)=ABS(KI(I,J)*DELI15)
      QO(I,J)=ABS(KO(I,J)*DELO15)
C CONTACT AREA RELATIONSHIPS                                             BA346200
      CALL LAGRAN(FRHOI(I,J),FTAB,ATAB,23,3,ASTARI(I,J),NERR)          BA346300
      IF(NERR.EQ.2) WRITE(LPT,2007) FRHOI(I,J)                          BA346400
      CALL LAGRAN(FRHOO(I,J),FTAB,ATAB,23,3,ASTARO(I,J),NERR)          BA346500
      IF(NERR.EQ.2) WRITE(LPT,2006) FRHOO(I,J)                          BA346600
      AI(I,J)=ASTARI(I,J)*(((3.*QI(I,J))/(2.*SIGMAI(I,J)))*((1.-NU1(I) BA346700
     1**2)/E1(I)+(1.-NU2(I)**2)/E2(I)))**(1./3.)                        BA346800
      AO(I,J)=ASTARO(I,J)*(((3.*QO(I,J))/(2.*SIGMAO(I,J)))*((1.-NU1(I) BA346900
     1**2)/E1(I)+(1.-NU2(I)**2)/E2(I)))**(1./3.)                        BA347000
      CALL LAGRAN(FRHOI(I,J),FTAB,BTAB,23,3,BSTARI(I,J),NERR)          BA347100
      IF(NERR.EQ.2) WRITE(LPT,2007) FRHOI(I,J)                          BA347200
      CALL LAGRAN(FRHOO(I,J),FTAB,BTAB,23,3,BSTARO(I,J),NERR)          BA347300
      IF(NERR.EQ.2) WRITE(LPT,2006) FRHOO(I,J)                          BA347400
      BI(I,J)=BSTARI(I,J)*(((3.*QI(I,J))/(2.*SIGMAI(I,J)))*((1.-NU1(I) BA347500
     1**2)/E1(I)+(1.-NU2(I)**2)/E2(I)))**(1./3.)                        BA347600
      BO(I,J)=BSTARO(I,J)*(((3.*QO(I,J))/(2.*SIGMAO(I,J)))*((1.-NU1(I) BA347700
     1**2)/E1(I)+(1.-NU2(I)**2)/E2(I)))**(1./3.)                        BA347800
      WRITE(LPT,3006) I,J,ALPHAI(I,J),ALPHAO(I,J),QO(I,J),QI(I,J),     BA347900
     1ASTARI(I,J),ASTARO(I,J),AI(I,J),AO(I,J),BSTARI(I,J),BSTARO(I,J), BA348000
     2BI(I,J),BO(I,J)                                                   BA348100
      IF(QMAXI(I).LT.ABS(QI(I,J))) GO TO 740                            BA348200
      GO TO 745                                                         BA348300
  740 QMAXI(I)=ABS(QI(I,J))                                             BA348400
      IMI(I)=I                                                          BA348500
      JMI(I)=J                                                          BA348600
  745 IF(QMAXO(I).LT.ABS(QO(I,J))) GO TO 746                            BA348700
      GO TO 750                                                         BA348800
  746 QMAXO(I)=ABS(QO(I,J))                                             BA348900
      IMO(I)=I                                                          BA349000
      JMO(I)=J                                                          BA349100
  750 CONTINUE                                                          BA349200
 2006 FORMAT(1X, 7HFRHOO =1PE13.6,23H IS OUTSIDE TABLE RANGE)
 2007 FORMAT(1X,7HFRHOI =1PE13.6,23H IS OUTSIDE TABLE RANGE)
 3006 FORMAT(1X,14HBEARING NUMBER,I2,9X,11HBALL NUMBER,I3,11X,7HALPHAI=1BA371500
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      1PE13.5,5X,7HALPHAO=1PE13.6,5X,7HOO     =1PE13.6,/1X,7HOI     =1PE13.6BA371700
      25,5X,7HASTARI=1PE13.5,5X,7HASTARO=1PE13.6,5X,7HAI     =1PE13.6,5X,7BA371800
      3HAO    =1PE13.6,/1X,7HBSTARI=1PE13.6,5X,7HBSTARO=1PE13.6,5X,7HBI  BA371900
      4  =1PE13.5,5X,7HBO     =1PE13.5)                                  BA372000
      RETURN
      END
@FOR,IS BLK9,BLK9
      SUBROUTINE BLK9
      COMMON /LB1/
     $             ALPHAS( 4)      ,ALPHA( 4)      ,ALPHAT( 4)          BA300900
     1,            ALPHMU( 4)      ,MUO( 4)        ,NUC( 4)             BA301000
     2,            NU1( 4)         ,NU2( 4)        ,D( 4)               BA301100
     4,            DI( 4)          ,DO( 4)         ,E1( 4)              BA301200
     4,            E2( 4)          ,EH( 4)         ,ES( 4)              BA301300
     4,            FS( 4)          ,PH( 4, 4)      ,LH( 4)              BA301400
     5,            KH( 4)          ,NH( 4)         ,FAH( 4)             BA301500
     7,            IH( 4)          ,JH( 4)         ,ZH( 4)              BA301600
     8,            SLH( 4)         ,TH( 4, 4)      ,DELA( 4)            BA301700
     9,            DELR( 4)        ,THETA( 4)      ,OMEAN( 4)           BA301800
     T,            GAMMAP( 4)      ,IRRC( 4)       ,OMEGA( 4)           BA301900
     1,            FI( 4)          ,FO( 4)         ,BOBAR( 4)           BA302000
     2,            R( 4)           ,M( 4)          ,NTS
      COMMON /LB2/
     $             PSI( 4,16)      ,ALPHAO( 4,16)  ,ALPHAI( 4,16)       BA302200
     1,            BETA( 4,16)     ,OMMOOM( 4,16)  ,OMROOM( 4,16)       BA302300
     2,            MG( 4,15)       ,SX( 4,16)      ,SZ( 4,16)           BA302400
     4,            FC( 4,15)       ,GAMMAI( 4,16)  ,GAMMAO( 4,16)       BA302500
     4,            SIGMAI( 4,16)   ,SIGMAO( 4,16)  ,FRHOO( 4,16)        BA302600
     4,            FRHOI( 4,16)    ,DSTARO( 4,16)  ,KO( 4,15)           BA302700
     5,            KI( 4,15)       ,DSTARI( 4,16)  ,W( 4,16)            BA302800
     7,            DELO( 4,16)     ,DELI( 4,16)                         BA302900
      COMMON /LB3/
     $             FTAB(23)        ,ATAB(23)       ,BTAB(23)            BA303000
     1,            DTAB(23)                                             BA303100
      COMMON /LB4/
     $             DO( 4,15)       ,DI( 4,16)      ,ASTARI( 4,16)       BA303200
     1,            ASTARO( 4,16)   ,AI( 4,16)      ,AO( 4,15)           BA303300
     2,            BSTARI( 4,16)   ,BSTARO( 4,16)  ,BI( 4,15)           BA303400
     4,            BO( 4,15)       ,EPSIO( 4,15)   ,EPSII( 4,16)        BA303500
     4,            OAEI( 4,16)     ,OAEO( 4,16)                         BA303500
     7,            W(4,16)         ,SUM( 4,5,4)    ,KI( 4,16)           BA303900
     8,            NPL( 4)         ,NTL( 4)        ,NAH( 4)             BA304000
     9,            AH( 4, 4)       ,NM( 4)         ,JSOOR( 4,16)        BA304100
      COMMON /LB5/
     $             NO( 4)                                               BA304200
     1,            EIY( 4)                         ,DELAH( 4)           BA304300
     2,            DELRH( 4)       ,THETAH( 4)     ,FRH( 4)             BA304400
     4,            MH( 4)          ,RXP( 4)        ,EP( 4)              BA304500
     4,            JB( 4)          ,JR( 4)         ,J( 4)               BA304600
     4,            IMO( 4)         ,JMO( 4)        ,IMI( 4)             BA304700
     6,            JMI( 4)         ,OMAXI( 4)      ,OMAXO( 4)           BA304800
     7,            ICHANG( 4)      ,SI( 4,15)      ,SO( 4,15)           BA304900
     8,            HO( 4)          ,IRC( 4)        ,HVH(4)              BA305000
      COMMON /LB6/
     $             STAB(4)         ,CTAB(4)        ,AETATB(4)
      COMMON /LB7/
     $             ITYPE( 4)       ,FBETA( 4)      ,ICO(4)              BA305300
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     $,               HF( 4)          ,HL( 4)         ,HS( 4)                 BA305400
     $,               HTOTAL( 4)                                              BA305500
     $,               MV( 4)          ,ML( 4)         ,MU(4)
     1,               MS( 4,16)       ,NS( 4,16)      ,LAMBDA( 4)
      COMMON /LB6/ ICR,LPT,SP,SQ,PI
      REAL MV,ML,MJ,MS,NS,LAMBDA,NM,MH,NO
      REAL MUO,NUO,NUI,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                              BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
      DO 910 I=1,NTS                                                          BA353100
  910 NM(I)=OMMOOM(I,1)*NH(I)                                                 BA353200
C CALCULATE BALL SPIN TO ROLL RATIO                                           BA353300
      IF(IRC(I).EQ.1)GO TO 920                                                BA353400
      GO TO 930                                                               BA353500
  920 CONTINUE                                                                BA353600
      DO 921 I=1,NTS                                                          BA353700
      NB=ZH(I)                                                                BA353800
      DO 921 J=1,NB                                                           BA353900
      OSOOR(I,J)=-(1.+GAMMAP(I)*COS(ALPHAI(I,J)))*TAN(ALPHAI(I,J)-BETA(IBA354000
     1,J))+GAMMAP(I)*SIN(ALPHAI(I,J))                                         BA354100
  921 CONTINUE                                                                BA354200
      GO TO 935                                                               BA354300
  930 CONTINUE                                                                BA354400
      DO 931 I=1,NTS                                                          BA354500
      NB=ZH(I)                                                                BA354600
      DO 931 J=1,NB                                                           BA354700
      OSOOR(I,J)=-(1.+GAMMAP(I)*COS(ALPHAO(I,J)))*TAN(ALPHAO(I,J)-BETA(IBA354800
     1,J))+GAMMAP(I)*SIN(ALPHAO(I,J))                                         BA354900
  931 CONTINUE                                                                BA355000
  935 CONTINUE                                                                BA355100
C CALCULATE BALL ROTATIONAL SPEED                                             BA355200
C FOR INNER RACEWAY ROTATION, NO=-NM                                          BA355300
      DO 940 I=1,NTS                                                          BA355400
  940 NO(I)=-NM(I)                                                            BA355500
C CALCULATE BALL NORMAL STRESS, X=0 Y=0 ,IF NOT,MUST RECODE                   BA355600
      DO 950 I=1,NTS                                                          BA355700
      NB=ZH(I)                                                                BA355800
      DO 950 J=1,NB                                                           BA355900
      SIGI=(3.*QI(I,J))/(PI*AI(I,J)*BI(I,J))
      SIGO=(3.*QO(I,J))/(PI*AO(I,J)*BO(I,J))
      WRITE(LPT,9001)SIGI,SIGO
 9001 FORMAT(1X,7HSIGI   =1PE13.6,5X,7HSIGO   =1PE13.6)
  950 CONTINUE                                                                BA356200
C CALCULATE SHAFT DEFLECTION ,BX=L/2                                          BA356100
      DO 970 I=1,NTS                                                          BA356400
      BX=LH(I)/2.                                                             BA356500
      EIY(I)=-(FRH(I)/6.1*(LH(I)**2*(2.*LH(I)-3.*BX)+BX**3)+                  BA356600
     1((MH(I)-TH(I,1))/2.)*(LH(I)-BX)**2+                                     BA356700
     2(PH(I,1)/6.)*(BX**2*(BX-3.*AH(I,1))-LH(I)**2*(3.*BX+3.*AH(I,1)-2.*BA356800
     3LH(I))+6.*BX*LH(I)*AH(I,1))                                             BA356900
      IF((I+1).LE.NTS) EIY(I)=EIY(I)+EH(I)*IH(I)*(DELRH(I+1)-THETAH(I+1)BA357000
     1*(LH(I)-BX))                                                            BA357100
  970 CONTINUE                                                                BA357200
C CALCULATE BEARING STIFFNESS                                                 BA357300
      DO 990 I=1,NTS                                                          BA357400
      BRH(I)=(4.77E+6)*ZH(I)*D(I)**.5*(COS(ALPHA(I)))**(5./2.)*DELRH(I   BA357500
```

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      1)                                                                BA357600
      WRITE(LPT,9002)NM(I),NO(I),EIY(I),SLH(I)
 9002 FORMAT(1X,7HNM     =1PE13.6,5X,7HNO     =1PE13.6,5X,7HEIY    =1PE13.6
     $,5X,7HSLH    =1PE13.6)
  980 CONTINUE
      RETURN
      END
@FOR,IS BLK10,BLK10
      SUBROUTINE BLK10
      COMMON /LB1/
     $               ALPHAS( 4)     ,ALPHA( 4)      ,ALPHAT( 4)          BA300900
     1,              ALPHMU( 4)     ,MUO( 4)        ,MUD( 4)             BA301000
     2,              NU1( 4)        ,NU2( 4)        ,D( 4)               BA301100
     4,              DI( 4)         ,DO( 4)         ,E1( 4)              BA301200
     4,              E2( 4)         ,EH( 4)         ,ES( 4)              BA301300
     4,              FS( 4)         ,PH( 4, 4)      ,LH( 4)              BA301400
     6,              KH( 4)         ,VH( 4)         ,FAH( 4)             BA301500
     7,              IH( 4)         ,JH( 4)         ,ZH( 4)              BA301600
     8,              SLH( 4)        ,TH( 4, 4)      ,DELA( 4)            BA301700
     9,              DELR( 4)       ,THETA( 4)      ,OMEAN( 4)           BA301800
     T,              GAMMAP( 4)     ,IRRC( 4)       ,OMEGA( 4)           BA301900
     1,              FI( 4)         ,FO( 4)         ,BOBAR( 4)           BA302000
     2,              R( 4)          ,M( 4)          ,NTS
      COMMON /LB2/
     $               PSI( 4,16)     ,ALPHAO( 4,15) ,ALPHAI( 4,16)       BA302200
     1,              BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)       BA302300
     2,              MG( 4,15)      ,SX( 4,16)     ,SZ( 4,15)           BA302400
     4,              FC( 4,15)      ,GAMMAI( 4,16) ,GAMMAO( 4,16)       BA302500
     4,              SIGMAI( 4,16)  ,SIGMAO( 4,15) ,FRHOO( 4,16)        BA302600
     4,              FRHOI( 4,15)   ,OSTARO( 4,15) ,KO( 4,16)           BA302700
     6,              KI( 4,15)      ,OSTARI( 4,16) ,W( 4,16)            BA302800
     7,              DELO( 4,16)    ,DELI( 4,16)                        BA302900
      COMMON /LB3/
     $               FTAB(23)       ,ATAB(23)       ,BTAB(23)            BA303000
     1,              DTAB(23)                                            BA303100
      COMMON /LB4/
     $               QO( 4,15)      ,QI( 4,16)     ,ASTARI( 4,16)       BA303200
     1,              ASTARO( 4,16)  ,AI( 4,15)     ,AO( 4,16)           BA303300
     2,              BSTARI( 4,15)  ,BSTARO( 4,15) ,BI( 4,16)           BA303400
     4,              BO( 4,15)      ,EPSIO( 4,15)  ,EPSII( 4,16)        BA303500
     4,              QAEI( 4,16)    ,QAEO( 4,16)                        BA303600
     7,              W(4,16)        ,SUM( 4,5,4)   ,XI( 4,16)           BA303900
     8,              NPL( 4)        ,NTL( 4)       ,NAH( 4)             BA304000
     9,              AH( 4, 4)      ,NM( 4)        ,OSOOR( 4,16)        BA304100
      COMMON /LB5/
     $               NO( 4)                                              BA304200
     1,              EIY( 4)                        ,DELAH( 4)           BA304300
     2,              DELRH( 4)      ,THETAH( 4)     ,FRH( 4)             BA304400
     4,              MH( 4)         ,RXP( 4)        ,EP( 4)              BA304500
     4,              UB( 4)         ,JR( 4)         ,J( 4)               BA304600
     4,              IMO( 4)        ,JMO( 4)        ,IMI( 4)             BA304700
     6,              JMI( 4)        ,OMAXI( 4)      ,OMAXO( 4)           BA304800
     7,              ICHANG( 4)     ,SI( 4,16)      ,SO( 4,16)           BA304900
     8,              HO( 4)         ,IRC( 4)        ,HVH(4)              BA305000
      COMMON /LB6/
     $               STAB(4)        ,CTAB(4)        ,AETATB(4)
      COMMON /LB7/
```

```
      RETURN
      END
@FOR,IS BL1112,BL1112
      SUBROUTINE BL1112
      COMMON /LB1/
     $          ALPHAS( 4)       ,ALPHA( 4)        ,ALPHAT( 4)          BA300900
     1,         ALPHMU( 4)       ,MUO( 4)          ,NUO( 4)             BA301000
     2,         NU1( 4)          ,NU2( 4)          ,D( 4)               BA301100
     4,         DI( 4)           ,DO( 4)           ,E1( 4)              BA301200
     4,         E2( 4)           ,EH( 4)           ,CS( 4)              BA301300
     4,         FS( 4)           ,PH( 4, 4)        ,LH( 4)              BA301400
     6,         AH( 4)           ,NH( 4)           ,FAH( 4)             BA301500
     7,         IH( 4)           ,JH( 4)           ,ZH( 4)              BA301600
     8,         SLH( 4)          ,TH( 4, 4)        ,DELA( 4)            BA301700
     9,         DELR( 4)         ,THETA( 4)        ,OMEAN( 4)           BA301800
     T,         GAMMAP( 4)       ,IRRC( 4)         ,OMEGA( 4)           BA301900
     1,         FI( 4)           ,FO( 4)           ,BOBAR( 4)           BA302000
     2,         R( 4)            ,H( 4)            ,NTS
      COMMON /LB2/
     $          PSI( 4,16)       ,ALPHAO( 4,16) ,ALPHAI( 4,16)          BA302200
     1,         BETA( 4,16)      ,OMMOOM( 4,15) ,OMROOM( 4,16)          BA302300
     2,         MU( 4,15)        ,SX( 4,16)     ,SZ( 4,15)              BA302400
     4,         FC( 4,15)        ,GAMMAI( 4,15) ,GAMMAO( 4,16)          BA302500
     4,         SIGMAI( 4,16)    ,SIGMAO( 4,16) ,FRHOO( 4,16)           BA302600
     4,         FRHOI( 4,15)     ,DSTARO( 4,16) ,KO( 4,15)              BA302700
     6,         KI( 4,15)        ,DSTARI( 4,16) ,W( 4,16)               BA302800
     7,         DELO( 4,16)      ,DELI( 4,15)                           BA302900
      COMMON /LB3/
     $          FTAB(23)         ,ATAB(23)         ,BTAB(23)            BA303000
     1,         DTAB(23)                                                BA303100
      COMMON /LB4/
     $          QO( 4,15)        ,QI( 4,16)        ,ASTARI( 4,16)       BA303200
     1,         ASTARO( 4,16)    ,AI( 4,16)        ,AO( 4,16)           BA303300
     2,         BSTARI( 4,16)    ,BSTARO( 4,16) ,BI( 4,15)              BA303400
     4,         BO( 4,15)        ,EPSIO( 4,16)  ,EPSII( 4,16)           BA303500
     4,         DAEI( 4,16)      ,DAEO( 4,16)                           BA303600
     7,         W(4,16)          ,SUM( 4,5,4)      ,KI( 4,15)           BA303900
     8,         NPL( 4)          ,NTL( 4)          ,NAH( 4)             BA304000
     9,         AH( 4, 4)        ,NM( 4)           ,DSOOR( 4,16)        BA304100
      COMMON /LB5/
     $          NO( 4)                                                  BA304200
     1,         EIY( 4)                            ,DELAH( 4)           BA304300
     2,         DELRH( 4)        ,THETAH( 4)       ,FRH( 4)             BA304400
     4,         MH( 4)           ,RXP( 4)          ,EP( 4)              BA304500
     4,         UB( 4)           ,JR( 4)           ,J( 4)               BA304600
     4,         IMO( 4)          ,JMO( 4)          ,IMI( 4)             BA304700
     6,         JMI( 4)          ,OMAXI( 4)        ,OMAXO( 4)           BA304800
     7,         ICHANG( 4)       ,SI( 4,15)        ,SO( 4,15)           BA304900
     8,         HO( 4)           ,IRC( 4)          ,NVH(4)              BA305000
      COMMON /LB6/
     $          STAB(4)          ,CTAB(4)          ,AETAT3(4)
      COMMON /LB7/
     $          LTYPE( 4)        ,FBETA( 4)        ,ICO(4)              BA305300
     $,         HF( 4)           ,HL( 4)           ,HS( 4)              BA305400
     $,         HTOTAL( 4)                                              BA305500
     $,         MV( 4)           ,ML( 4)           ,MU(4)
     1,         M.( 4,15)        ,VS( 4,15)        ,[illegible]( 4)
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      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      REAL MV,ML,MJ,MS,NS,LAMBDA,NN,MH,NO
      REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                        BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
C MV     = VISCOUS FRICTION TORQUE                                      BA361700
      DO 1110 I=1,NTS                                                   BA361800
      VN=NJO(I)*NH(I)                                                   BA361900
      IF(VN.LE.3.2) GO TO 1105                                          BA362000
      MV(I)=0.0291*VN*DMEAN(I)**3                                       BA362100
      GO TO 1110                                                        BA362200
 1105 MV(I)=(3.492E-3 )*FLOAT(LTYPE(I))*DMEAN(I)**3                     BA362300
 1110 CONTINUE                                                          BA362400
C ML     = TORQUE DUE TO APPLIED LOAD                                   BA362500
      DO 1150 I=1,NTS                                                   BA362600
      FBETA(I)=0.9*FAH(I)*COT(ALPHA(I))-0.1*FRH(I)                      BA362700
      IF(FBETA(I).LT.FRH(I)) FBETA(I)=FRH(I)                            BA362800
      ML(I)=SP*(FS(I)/CS(I))**SQ*FBETA(I)*DMEAN(I)                      BA362900
 1150 CONTINUE                                                          BA363000
C MS     = TORQUE DUE TO BALL SPINNING                                  BA363100
      DO 1190 I=1,NTS                                                   BA363200
      NB=ZH(I)                                                          BA363300
      DO 1190 J=1,NB                                                    BA363400
      IF(IRC(I).EQ.0) GO TO 1185                                        BA363500
      MS(I,J)=(3.*MJ(I)*QI(I,J)*AI(I,J)*EPSII(I,J))/8.                  BA363600
      GO TO 1190                                                        BA363700
 1185 CONTINUE                                                          BA363800
      MS(I,J)=(3.*MJ(I)*QO(I,J)*AO(I,J)*EPSIO(I,J))/8.                  BA363900
 1190 CONTINUE                                                          BA364000
      DO 1210 I=1,NTS                                                   BA364100
      HF(I)=0.0404*NH(I)*MV(I)                                          BA364200
      HL(I)=0.0404*NH(I)*ML(I)                                          BA364300
 1210 CONTINUE                                                          BA364400
      DO 1220 I=1,NTS                                                   BA364500
      NB=ZH(I)                                                          BA364600
      DO 1220 J=1,NB                                                    BA364700
      NS(I,J)=DSQOR(I,J)*NO(I)*(-1./GAMMAP(I))                          BA364800
 1220 CONTINUE                                                          BA364900
      DO 1230 I=1,NTS                                                   BA365000
      HS(I)=0.                                                          BA365100
      NB=ZH(I)                                                          BA365200
      DO 1230 J=1,NB                                                    BA365300
      HS(I)=HS(I)+0.0404*NS(I,J)*MS(I,J)                                BA365400
 1230 CONTINUE                                                          BA365500
C HF     = HEAT DUE TO FRICTION                                         BA365600
C HL     = HEAT DUE TO LOAD                                             BA365700
C HS     = HEAT DUE TO BALL SPINNING                                    BA365800
      DO 1250 I=1,NTS                                                   BA365900
      HTOTAL(I)=ABS(HF(I))+ABS(HL(I))+ABS(HS(I))
      WRITE(LPT,2033) I,HF(I),HL(I),HS(I),HTOTAL(I)                     BA366100
 1250 CONTINUE                                                          BA366200
 2033 FORMAT(1X,14HBEARING NUMBER,I2,9X,7HHF     =1PE13.6,5X,7HHL     =1PEBA370200
     113.6,5X,7HHS     =1PE13.6,5X,7HHTOTAL=1PE13.6)                    BA370300
      RETURN
      END
@FOR,IS BLOCK.BLOCK
```

```
      BLOCK DATA
      COMMON /LB1/
     $       ALPHAS( 4)     ,ALPHA( 4)     ,ALPHAT( 4)            BA300900
     1,      ALPHMU( 4)     ,MU0( 4)       ,MU3( 4)               BA301000
     2,      MU1( 4)        ,MU2( 4)       ,D( 4)                 BA301100
     4,      DI( 4)         ,DO( 4)        ,EI( 4)                BA301200
     4,      E2( 4)         ,EH( 4)        ,ES( 4)                BA301300
     4,      FS( 4)         ,PH( 4, 4)     ,LH( 4)                BA301400
     6,      KH( 4)         ,NH( 4)        ,FAH( 4)               BA301500
     7,      IH( 4)         ,JH( 4)        ,ZH( 4)                BA301600
     9,      SLH( 4)        ,TH( 4, 4)     ,DELA( 4)              BA301700
     9,      DELR( 4)       ,THETA( 4)     ,OMEAN( 4)             BA301800
     T,      GAMMAP( 4)     ,IRRC( 4)      ,OMEGA( 4)             BA301900
     1,      FI( 4)         ,FO( 4)        ,BOBAR( 4)             BA302000
     2,      R( 4)          ,N( 4)         ,NTS
      COMMON /LB2/
     $       PSI( 4,16)     ,ALPHAO( 4,16) ,ALPHAI( 4,16)         BA302200
     1,      BETA( 4,16)    ,OMMOOM( 4,16) ,OMROOM( 4,16)         BA302300
     2,      MG( 4,15)      ,SX( 4,16)     ,SZ( 4,15)             BA302400
     4,      FC( 4,15)      ,GAMMAI( 4,15) ,GAMMAO( 4,16)         BA302500
     4,      SIGMAI( 4,16)  ,SIGMAO( 4,16) ,FRHOO( 4,16)          BA302600
     4,      FRHOI( 4,16)   ,DSTARO( 4,15) ,KO( 4,15)             BA302700
     6,      KI( 4,15)      ,DSTARI( 4,16) ,W( 4,16)              BA302800
     7,      DELO( 4,16)    ,DELI( 4,16)                          BA302900
      COMMON /LB3/
     $       FTAB(23)       ,ATAB(23)      ,BTAB(23)              BA303000
     1,      DTAB(23)                                             BA303100
      COMMON /LB4/
     $       DO( 4,15)      ,DI( 4,15)     ,ASTARI( 4,16)         BA303200
     1,      ASTARO( 4,15)  ,AI( 4,16)     ,AO( 4,16)             BA303300
     2,      BSTARI( 4,15)  ,BSTARO( 4,16) ,BI( 4,15)             BA303400
     4,      BO( 4,15)      ,EPSIO( 4,16)  ,EPSII( 4,16)          BA303500
     4,      DAEI( 4,16)    ,DAEO( 4,16)                          BA303600
     7,      W(4,16)        ,SUM( 4,5,4)   ,KI( 4,15)             BA303900
     8,      NPL( 4)        ,NTL( 4)       ,NAH( 4)               BA304000
     9,      AH( 4, 4)      ,NH( 4)        ,DSOOR( 4,16)          BA304100
      COMMON /LB5/
     $       NO( 4)                                               BA304200
     1,      EIY( 4)                       ,DELAH( 4)             BA304300
     2,      DELRH( 4)      ,THETAH( 4)    ,FRH( 4)               BA304400
     4,      MH( 4)         ,RXP( 4)       ,EP( 4)                BA304500
     4,      UB( 4)         ,JR( 4)        ,J( 4)                 BA304600
     4,      IMO( 4)        ,JMO( 4)       ,IMI( 4)               BA304700
     6,      JMI( 4)        ,QMAXI( 4)     ,QMAXO( 4)             BA304800
     7,      ICHANG( 4)     ,SI( 4,16)     ,SO( 4,15)             BA304900
     8,      HO( 4)         ,IRC( 4)       ,AVH(4)                BA305000
      COMMON /LB6/
     $       STAB(4)        ,CTAB(4)       ,AETAI3(4)
      COMMON /LB7/
     $       LTYPE( 4)      ,FBETA( 4)     ,ICO(4)                BA305300
     $,      HF( 4)         ,HL( 4)        ,HS( 4)                BA305400
     $,      HTOTAL( 4)                                           BA305500
     $,      MV( 4)         ,ML( 4)        ,MU(4)
     1,      MS( 4,15)      ,NS( 4,16)     ,LAMBDA( 4)
      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      COMMON /SLOAD/
     $       SELX( 5)       ,SELY( 5)      ,SELALP( 5)
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      REAL MV,ML,MU,MS,NS,LAMBDA,NM,MH,NO
      REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER ZH                                                        BA305600
      DATA SP/0.00115/,SG/0.33/                                         BA306200
C FOR ANGULAR CONTACT BALL BEARINGS,SP=0.00115,SG=0.33                   BA306300
      DATA ICR/5/,LPT/6/
      DATA PI/3.14159/                                                  BA306500
      DATA STAB/0.2,0.5,1.0,2.0/                                        BA306600
      DATA CTAB/0.098,0.095,0.088,0.065/                                BA306700
      DATA AETATB/0.648,0.642,0.620,0.548/                              BA306800
C IRC  = 1 FOR INNER RACE CONTROL = 0 FOR OUTER                          BA306900
      DATA IRC/1,1,1,1/ ,ICHANS/4*0/
      DATA           FTAB/0.,0.1075,0.3204,0.4795,0.5916,0.6716,0.7332BA307100
     1,0.7948,0.83495,0.87366,0.90999,0.93657,0.95738,0.97290,0.983797, BA307200
     20.993902,0.995112,0.997300,0.9981847,0.9989156,0.9994785,0.9998527BA307300
     3,1./                                                              BA307400
      DATA           ATAB/1.,1.0750,1.2623,1.4555,1.6440,1.8258,2.011,BA307500
     12.265,2.494,2.800,3.233,3.733,4.395,5.257,6.446,8.052,10.222,     BA307600
     212.739,14.839,17.974,23.55,37.38,1.E+30/                          BA307700
      DATA           BTAB/1.,0.9318,0.8114,0.7273,0.6587,0.6245,0.5881BA307800
     1,0.5480,0.5186,0.4863,0.4499,0.4166,0.3830,0.3490,0.3150,0.2814,  BA307900
     20.2497,0.2232,0.2072,0.18822,0.15442,0.13050,0./                  BA308000
      DATA           DTAB/1.,0.9974,0.9751,0.9429,0.9377,0.8733,0.8394BA308100
     1,0.7961,0.7602,0.7169,0.6536,0.6112,0.5551,0.4960,0.4352,0.3745,  BA308200
     20.3176,0.2705,0.2427,0.2136,0.17167,0.11995,0./                   BA308300
C     STATIC EQUIVALENT LOAD DETERMINATION TABLES = F(CONTACT ANGLE)
      DATA SELALP/20.,25.,30.,35.,40./
      DATA SELK/0.5,0.5,0.5,0.5,0.5/
      DATA SELY/0.42,0.38,0.33,0.29,0.26/
      END
@FOR,IS CALFUN,CALFUN
      SUBROUTINE CALFUN                                                 BA311900
      COMMON /LB1/
     $              ALPHAS( 4)    ,ALPHA( 4)     ,ALPHAT( 4)            BA300900
     1,             ALPHMU( 4)    ,MUO( 4)       ,NUO( 4)               BA301000
     2,             NU1( 4)       ,NU2( 4)       ,D( 4)                 BA301100
     4,             DI( 4)        ,DO( 4)        ,E1( 4)                BA301200
     4,             E2( 4)        ,EH( 4)        ,CS( 4)                BA301300
     4,             FS( 4)        ,PH( 4, 4)     ,LH( 4)                BA301400
     6,             KH( 4)        ,NH( 4)        ,FAH( 4)               BA301500
     7,             IH( 4)        ,JH( 4)        ,ZH( 4)                BA301600
     8,             SLH( 4)       ,TH( 4, 4)     ,DELA( 4)              BA301700
     9,             DELR( 4)      ,THETA( 4)     ,OMEAN( 4)             BA301800
     T,             GAMMAP( 4)    ,IRRC( 4)      ,OMEGA( 4)             BA301900
     1,             FI( 4)        ,FO( 4)        ,BDBAR( 4)             BA302000
     2,             R( 4)         ,M( 4)         ,NTS
      COMMON /LB2/
     $              PSI( 4,16)    ,ALPHAO( 4,16) ,ALPHAI( 4,16)         BA302200
     1,             BETA( 4,16)   ,OMMOOM( 4,16) ,OMROOM( 4,16)         BA302300
     2,             MG( 4,16)     ,SX( 4,16)     ,SZ( 4,16)             BA302400
     4,             FC( 4,16)     ,GAMMAI( 4,16) ,GAMMAO( 4,16)         BA302500
     4,             SIGMAI( 4,16) ,SIGMAO( 4,16) ,FRHOO( 4,16)          BA302600
     4,             FRHOI( 4,16)  ,DSTARO( 4,16) ,KO( 4,16)             BA302700
     6,             KI( 4,16)     ,DSTARI( 4,16) ,W( 4,16)              BA302800
     7,             DELO( 4,16)   ,DELI( 4,16)                          BA302900
      COMMON /LB3/
     $              FTAB(23)      ,ATAB(23)      ,BTAB(23)              BA303000
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     1,              DTAB(23)                                               BA303100
      COMMON /LB4/
     $               QO( 4,15)      ,QI( 4,16)      ,ASTARI( 4,16)          BA303200
     1,              ASTARO( 4,16)  ,AI( 4,16)      ,AO( 4,16)              BA303300
     2,              BSTARI( 4,16)  ,BSTARO( 4,16)  ,BI( 4,16)              BA303400
     4,              BO( 4,15)      ,EPSIO( 4,15)   ,EPSII( 4,16)           BA303500
     4,              DAEI( 4,16)    ,DAEO( 4,16)                            BA303600
     7,              W(4,15)        ,SUM(4,5,4)     ,XI( 4,15)
     8,              NPL( 4)        ,NTL( 4)        ,NAH( 4)                BA304000
     9,              AH( 4, 4)      ,NM( 4)         ,DSOOR( 4,16)           BA304100
      COMMON /LB5/
     $               NO( 4)                                                 BA304200
     1,              EIY( 4)                        ,DELAH( 4)              BA304300
     2,              DELRH( 4)      ,THETAH( 4)     ,FRH( 4)                BA304400
     4,              MH( 4)         ,RXP( 4)        ,EP( 4)                 BA304500
     4,              JB( 4)         ,JR( 4)         ,J( 4)                  BA304600
     4,              IMO( 4)        ,JMO( 4)        ,IMI( 4)                BA304700
     6,              JMI( 4)        ,QMAXI( 4)      ,QMAXO( 4)              BA304800
     7,              ICHANG( 4)     ,SI( 4,16)      ,SO( 4,16)              BA304900
     8,              HO( 4)         ,IRC( 4)        ,HVH(4)                 BA305000
      COMMON /LB6/
     $               STAB(4)        ,CTAB(4)        ,AETAT3(4)
      COMMON /LB7/
     $               LTYPE( 4)      ,FBETA( 4)      ,ICO(4)                 BA305300
     $,              HF( 4)         ,HL( 4)         ,HS( 4)                 BA305400
     $,              HTOTAL( 4)                                             BA305500
     $,              MV( 4)         ,ML( 4)         ,MJ(4)
     1,              MS( 4,16)      ,NS( 4,16)      ,LAMBDA( 4)
      COMMON /LB8/ ICR,LPT,SP,SQ,PI
      COMMON /NLIN/
     $               X(20)          ,F(20)          ,AJINV(20,20)
     1,              WORK(950)      ,JC(20)         ,ISYS
     $,              N              ,I              ,J
      DOUBLE PRECISION X,F,AJINV,WORK
      REAL MV,ML,MJ,MS,NS,LAMBDA,NM,MH,NO
      REAL MUO,NUO,NU1,NU2,IH,JH,LH,KH,NH,MG,M,KO,KI
      INTEGER Z4                                                            BA305600
      TAN(Q)=SIN(Q)/COS(Q)
      COT(Q)=COS(Q)/SIN(Q)
      DIMENSION TERM(5,2,2)                                                 BA312500
      GO TO(1,2),ISYS
    1 CONTINUE                                                              BA312700
C F(1)   = EQUATION (4.1) OF CHIOU      X(1) = V                            BA312800
C F(2)   = EQUATION (4.2) OF CHIOU      X(2) = W                            BA312900
C F(3)   = EQUATION (4.3) OF CHIOU      X(3) = DELO                         BA313000
C F(4)   = EQUATION (4.4) OF CHIOU      X(4) = DELI                         BA313100
C F(5)   = EQUATION (4.12+4.15) OF CHIOU     X(5)=M3
C F(6)   = EQUATION (7.1) OF CHIOU           X(6)=ALPHAI
C F(7)   = EQUATION (7.2) OF CHIOU           X(7)=ALPHAO
C F(8)   = EQUATION (4.16) OF CHIOU          X(8)=FC
      DO 10 II=1,8
      IF(ABS(X(II)).LT.1.E-10) X(II)=1.E-10
      IF(X(II).GT.1.E+10) X(II)=1.E+10
      IF(X(II).LT.-1.E+10) X(II)=-1.E+10
   10 CONTINUE
      S3=1.
      IF(X(3).LT.0.) S3=-1.
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      S4=1.
      IF(X(4).LT.0.) S4=-1.
      IF(ABS(X(3)).GT.0.0001)X(3)=S3*0.0001
      IF(ABS(X(4)).GT.0.0001)X(4)=S4*0.0001
      F3T1=S3*ABS(X(3))**1.5
      F3T2=S4*ABS(X(4))**1.5
      F4T1=S3*ABS(X(3))**1.5
      F4T2=S4*ABS(X(4))**1.5
      DEGMAX=90./57.2957795
      IF(X(6).GT.DEGMAX) X(6)=DEGMAX
      IF(X(6).LT.-DEGMAX) X(6)=-DEGMAX
      IF(X(7).GT.DEGMAX) X(7)=DEGMAX
      IF(X(7).LT.-DEGMAX) X(7)=-DEGMAX
      F(1)=(SX(I,J)-X(2))**2+(SZ(I,J)-X(1))**2-((FI(I)-.5)*D(I)+X(4))**2BA313200
      F(2)=X(2)**2+X(1)**2-((FO(I)-.5)*D(I)+X(3))**2                    BA313300
      F(3)=((2.*LAMBDA(I)*X(5)    *X(1))/D(I)-KO(I,J)*F3T1*X(2))/
     1((FO(I)-.5)*D(I)+X(3))+(KI(I,J)*F3T2*(SX(I,J)-X(2))-
     2((2.*(1.-LAMBDA(I))*X(5)    )/D(I))*(SZ(I,J)-X(1)))/((FI(I)-.5)*  BA313600
     3 D(I)+X(4))                                                       BA313700
      F(4)=(KO(I,J)*F4T1*X(1)+((2.*LAMBDA(I)*X(5)    *X(2))/D(I)))/
     1 ((FO(I)-.5)*D(I)+X(3))-(KI(I,J)*F4T2*(SZ(I,J)-X(1))+
     2((2.*(1.-LAMBDA(I))*X(5)    )/D(I))*(SX(I,J)-X(2)))/((FI(I)-.5)*  BA314000
     3 D(I)+X(4))-X(8)
      F(5)=JH(I)*OMROOM(I,J)*OMMOOM(I,J)*OMEGA(I)**2*SIN(BETA(I,J))-X(5)
      F(6)=(SZ(I,J)-X(1))/((FI(I)-0.5) *D(I)+X(4))-COS(X(6))
      F(7)=(X(1)/((FO(I)-0.5)*D(I)+X(3)))-COS(X(7))
      F(8)=0.001295*M(I)*DMEAN(I)*OMEGA(I)**2*OMMOOM(I,J)**2-X(8)
      GO TO 999                                                         BA314200
    2 CONTINUE                                                          BA314300
C X(1)THROUGH X(NTS) = DELAH(I)                                         BA314400
C X(NTS+1) THROUGH X(2*NTS) = DELRH(I)                                  BA314500
C X(2*NTS+1) THROUGH X(3*NTS) = THETAH(I)                               BA314600
C X(3*NTS+1) THROUGH X(4*NTS) = FRH(I)                                  BA314700
C X(4*NTS+1) THROUGH X(5*NTS) = MH(I)                                   BA314800
      NEQ=5*NTS                                                         BA314900
      DO 100 II=1,NEQ
      IF(ABS(X(II)).LT.1.E-10) X(II)=1.E-10
      IF(X(II).GT.1.E+10) X(II)=1.E+10
      IF(X(II).LT.-1.E+10) X(II)=-1.E+10
  100 CONTINUE
      KNT=0                                                             BA315000
      DO 200 II=1,NTS                                                   BA315100
      F(II*KNT+1)=FAH(II)-SUM(II,1,4)-SUM(II,1,1)*X(II)+SUM(II,1,2)*X(NTBA315200
     1S+II)-SUM(II,1,3)*X(2*NTS+II)                                     BA315300
      F(II*KNT+2)=X(3*NTS+II)-SUM(II,2,4)-SUM(II,2,1)*X(II)-SUM(II,2,2)*BA315400
     1X(NTS+II)-SUM(II,2,3)*X(2*NTS+II)                                 BA315500
      F(II*KNT+3)=X(4*NTS+II)-SUM(II,3,4)-SUM(II,3,1)*X(II)+SUM(II,3,2)*BA315600
     1X(NTS+II)-SUM(II,3,3)*X(2*NTS+II)                                 BA315700
      IF(II.EQ.1) GO TO 110                                             BA315800
      TERM(II,1,1)=(IH(II-1)/LH(II-1)**2)*(X(2*NTS+II-1)+X(2*NTS+II)+   BA315900
     1(2./LH(II-1))*(X(NTS+II-1)-X(NTS+II)))                            BA316000
      GO TO 111                                                         BA316100
  110 CONTINUE                                                          BA316200
      TERM(II,1,1)=0.                                                   BA316300
  111 IF(II.EQ.NTS) GO TO 112                                           BA316400
      TERM(II,1,2)=(IH(II)/LH(II)**2)*(X(2*NTS+II)+X(2*NTS+II+1)+       BA316500
     1(2./LH(II))*(X(NTS+II)-X(NTS+II+1)))                              BA316500
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      GO TO 113                                                         BA316700
  112 TERM(II,1,2)=(IH(II)/LH(II)**2)*(X(2*NTS+II)+(2./LH(II))*X(NTS+II)BA316800
     1)                                                                 BA316900
  113 CONTINUE                                                          BA317000
      IF(II.EQ.1) GO TO 120                                             BA317100
      TERM(II,2,1)=(IH(II-1)/LH(II-1))*(X(2*NTS+II-1)+2.*X(2*NTS+II)+   BA317200
     1(3./LH(II-1))*(X(NTS+II-1)-X(NTS+II)))                            BA317300
      GO TO 121                                                         BA317400
  120 TERM(II,2,1)=0.                                                   BA317500
  121 IF(II.EQ.NTS) GO TO 122                                           BA317600
      TERM(II,2,2)=(IH(II)/LH(II))*(2.*X(2*NTS+II)+X(2*NTS+II+1)+       BA317700
     1(3./LH(II))*(X(NTS+II)-X(NTS+II+1)))                              BA317800
      GO TO 123                                                         BA317900
  122 TERM(II,2,2)=(IH(II)/LH(II))*(2.*X(2*NTS+II)+(3./LH(II))*X(NTS+II)BA318000
     1)                                                                 BA318100
  123 CONTINUE                                                          BA318200
      F(II*KNT+4)=-X(3*NTS+II)+SUM(II,4,1)+SUM(II,4,2)+SUM(II,4,3)-     BA318300
     1SUM(II,4,4)+6.*EH(II)*(TERM(II,1,1) -TERM(II,1,2))                BA318400
      F(II*KNT+5)=-X(4*NTS+II)+SUM(II,5,1)-SUM(II,5,2)+SUM(II,5,3)-     BA318500
     1SUM(II,5,4)+2.*EH(II)*(TERM(II,2,1)+TERM(II,2,2))                 BA318600
      KNT=KNT+1
  200 CONTINUE                                                          BA318700
  999 RETURN                                                            BA318800
      END                                                               BA318900
@FOR,IS NLINEQ,NLINEQ
      SUBROUTINE NLINEQ
      COMMON /NLIN/
     $            X(20)           ,F(20)          ,AJINV(20,20)
     1,           W(950)          ,JC(20)         ,ISYS
     $,           N               ,IBEAR          ,JBALL
      DOUBLE PRECISION X,F,AJINV,W
C-----------------------------------------------------------------------BA374600
      DIMENSION V(2)                                                    BA374700
C-----------------------------------------------------------------------BA374900
C  SET VARIOUS PARAMETERS                                               BA375000
      DATA DSTEP,DMAX,ACC,MAXFUN,IPRINT/.00005,1000000.,.05,300,3/
      DSTEP=0.001
      DMAX=10000.
      LPT=5
      NTT=0
      MAXC=0                                                            BA375100
C  'MAXC' COUNTS THE NUMBER OF CALLS OF CALFUN                          BA375200
      NT=N + 4                                                          BA375300
      NTEST = NT                                                        BA375400
C  'NT' AND NTEST CAUSE AN ERROR RETRUN IF F(X) DOES NOT DECREASE       BA375500
      DTEST = FLOAT(N + N) - 0.5                                        BA375600
C  'DTEST' IS USED TO MAINTAIN LINEAR IUDEPENDENCE                      BA375700
      NX=N*N                                                            BA375800
      NF=NX + N                                                         BA375900
      NW=NF + N                                                         BA376000
      MW = NW + N                                                       BA376100
      NDC=MW + N                                                        BA376200
      ND=NDC + N                                                        BA376300
C  THESE PARAMETERS SEPARATE THE WORKING SPACE ARRAY W                  BA376400
      FMIN=0.                                                           BA376500
C  USUALLY 'FMIN' IS THE LEAST CALCULATED VALUE OF F(X) AND THE BEST X  BA376600
C  IS IN W(NX + 1) TO W(NX + N)                                         BA376700
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      DD=0.                                                             BA376800
C     USUALLY DD IS THE SQUARE OF THE CURRENT STEP LENGTH               BA376900
      DSS=DSTEP*DSTEP                                                   BA377000
      DM=DMAX*DMAX                                                      BA377100
      DMM=4.*DM                                                         BA377200
      IS=5                                                              BA377300
C     'IS' CONTROLS A 'GO TO' STATEMENT FOLLOWING A CALL OF CALFUN      BA377400
      TINC=1.                                                           BA377500
C     'TINC' IS USED IN THE CRITERION TO INCREASE THE STEP LENGTH       BA377600
C      START A NEW PAGE FOR PRINTING                                    BA377700
      IF(IPRINT)1,1,85                                                  BA377800
   85 WRITE(LPT,86)
   86 FORMAT(1H1)                                                       BA378000
C     CALL THE SUBROUTINE CALFUN                                        BA378100
    1 MAXC=MAXC + 1                                                     BA378200
      CALL CALFUN
C     TEST FOR CONVERGENCE                                              BA378400
      FSQ=0.                                                            BA378500
      DO 2 I=1,N                                                        BA378600
      FSQ=FSQ + F(I)*F(I)                                               BA378700
    2 CONTINUE                                                          BA378800
      IF(FSQ - ACC) 3,3,4                                               BA378900
C     PROVIDE PRINTING OF FINAL SOLUTION IF REQUESTED                   BA379000
    3 CONTINUE
    6 WRITE(LPT,7)MAXC
    7 FORMAT(///5X,47HTHE FINAL SOLUTION CALCULATED BY NS01A REQUIRED   BA379300
     1I5,24H CALLS OF CALFUN, AND IS  )                                 BA379400
      WRITE(LPT,8)(I,X(I),F(I),I=1,N)
    8 FORMAT(//4X,1HI,7X,4HX(I),12X,4HF(I)//(I5,2E17.8))                BA379600
      WRITE(LPT,9)FSQ
    9 FORMAT(/5X,21HTHE SUM OF SQUARES IS  E17.8)                       BA379800
    5 RETURN                                                            BA379900
C     TEST FOR ERROR RETURN BECAUSE F(X) DOES NOT DECREASE              BA380000
    4 GO TO (10,11,11,10,11),IS                                         BA380100
   10 IF(FSQ - FMIN)15,20,20                                            BA380200
   20 IF(DD - DSS)12,12,11                                              BA380300
   12 NTEST=NTEST - 1                                                   BA380400
      DSTEP=DSTEP/10.
      IF(DSTEP.LT.0.000001) DSTEP=0.000001
      DSS=DSTEP*DSTEP
      IF(NTEST)13,14,11                                                 BA380500
   14 WRITE(LPT,16)NT
   16 FORMAT(///5X,31HERROR RETRUN FROM NS01A BECAUSE  I5,              BA380700
     1 48H CALLS OF CALFUN FAILED TO IMPROVE THE RESIDUALS    )         BA380800
   17 DO 18 I=1,N                                                       BA380900
      X(I)=W(NX + I)                                                    BA381000
      F(I)=W(NF + I)                                                    BA381100
   18 CONTINUE                                                          BA381200
      FSQ=FMIN                                                          BA381300
      GO TO 3                                                           BA381400
C     ERROR RETURN BECAUSE A NEW JOCOBIAN IS UNSUCCESSFUL               BA381500
   13 WRITE(LPT,19)                                                     BA381600
   19 FORMAT(///5X,76HERROR RETURN FROM NS01A BECAUSE F(X) FAILED TO DECBA381700
     1REASE USING A NEW JACOBIAN    )                                   BA381800
      GO TO 17                                                          BA381900
   15 NTEST=NT                                                          BA382000
C     TEST WHETHER THERE HAVE BEEN MAXFUN CALLS OF CALFUN               BA382100
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   11 IF(MAXFUN - MAXC)21,21,22                                       BA382200
   21 WRITE(LPT,23)MAXC                                                BA3 63
   23 FORMAT(///5X,47HERROR RETURN FROM NS01A BECAUSE THERE HAVE BEEN  BA382400
     1 I5, 16H CALLS OF CALFUN )                                       BA382500
      IF(FSQ - FMIN)3,17,17                                            BA382600
C     PROVIDE PRINTING IF REQUESTED                                    BA382700
   22 IF(IPRINT)24,24,25                                               BA382800
   25 WRITE(LPT,26)MAXC                                                
   26 FORMAT(///5X,6HAT THE  I5,25H TH CALL OF CALFUN WE HAVE  )       BA383000
      WRITE(LPT,6)(I,X(I),F(I),I=1,N)
      WRITE(LPT,9)FSQ
   24 GO TO (27,28,29,67,30),IS                                        BA383300
C     STORE THE RESULT OF THE INITIAL CALL OF CALFUN                   BA383400
   30 FMIN=FSQ                                                         BA383500
      DO 31 I=1,N                                                      BA383600
      W(NX + I)=X(I)                                                   BA383700
      W(NF + I)=F(I)                                                   BA383800
   31 CONTINUE                                                         BA383900
C     CALCULATE A NEW JACOBIAN APPROXIMATION                           BA384000
   32 IC=0                                                             BA384100
      IS=3                                                             BA384200
   33 IC=IC + 1                                                        BA384300
      X(IC)=X(IC) + DSTEP                                              BA384400
      GO TO 1                                                          BA384500
   29 K=IC                                                             BA384600
      DO 34 I=1,N                                                      BA384700
      W(K)=(F(I) - W(NF + I))/DSTEP                                    BA384800
      K=K + N                                                          BA384900
   34 CONTINUE                                                         BA385000
      X(IC)=W(NX + IC)                                                 BA385100
      IF(IC - N)33,35,35                                               BA385200
C     CALCULATE THE INVERSE OF THE JACOBIAN AND SET THE DIRECTION MATRIX BA385300
   35 K=0                                                              BA385400
      DO 36 I=1,N                                                      BA385500
      DO 37 J=1,N                                                      BA385600
      K=K + 1                                                          BA385700
      AJINV(I,J)=W(K)                                                  BA385800
      W(ND + K)=0.                                                     BA385900
   37 CONTINUE                                                         BA386000
      W(NDC + K + I)=1.                                                BA386100
      W(NDC + I)=1. + FLOAT(N - I)                                     BA386200
   36 CONTINUE                                                         BA386300
C--------------------------------------------------------------------  BA386400
      V(1)=1.                                                          BA386500
      CALL GJR(AJINV,N,N,N,N,ICHK,JC,V)                                BA386600
      IF(ICHK.NE.0) GO TO 100                                          BA386700
C--------------------------------------------------------------------  BA386800
      WRITE(LPT,999)
  999 FORMAT(/2X,'*** JUST CAME OUT OF INVERSE ROUTINE ***'/)          BA387000
C     START ITERATION BY PREDICTION THE DESCENT AND NEWTON MINIMA      BA387100
   38 DS=0.                                                            BA387200
      DN=0.                                                            BA387300
      SP=0.                                                            BA387400
      DO 39 I=1,N                                                      BA387500
      X(I)=0.                                                          BA387600
      F(I)=0.                                                          BA387700
      K=I                                                              BA387800
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      DO 40 J=1,N                                                       BA387900
      X(I)=X(I) - W(K)*W(NF + J)                                        BA388000
      F(I)=F(I) - AJINV(I,J)*W(NF + J)                                  BA388100
      K = K + N                                                         BA388200
   40 CONTINUE                                                          BA388300
      DS=DS + X(I)*X(I)                                                 BA388400
      DN=DN + F (I)*F(I)                                                BA388500
      SP=SP + X(I)*F(I)                                                 BA388600
   39 CONTINUE                                                          BA388700
C  TEST WHETHER A NEARBY STATIONARY POINT IS PREDICTED                  BA388800
      IF(ABS(FMIN).GT.1.0E+18) FMIN=1.0E+18
      IF(ABS(DMM).GT.1.0E+18) DMM=1.0E+18
      IF(ABS(DS).GT.1.0E+18) DS=1.0E+18
      IF(FMIN*FMIN - DMM*DS)41,41,42                                    BA388900
C  IF SO THEN RETURN OR REVISE JACOBIAN                                 BA389000
   42 GO TO(43,43,44),IS                                                BA389100
   44 WRITE(LPT,45)
   45 FORMAT(///5X,78HERROR RETURN FROM NSO1A BECAUSE A NEARBY STATIONARBA389300
     1Y POINT OF F(X) IS PREDICTED    )                                 BA389400
      GO TO 17                                                          BA389500
   43 NTEST=0                                                           BA389600
      DO 46 I=1,N                                                       BA389700
      X(I)=W(NX + I)                                                    BA389800
   46 CONTINUE                                                          BA389900
      GO TO 32                                                          BA390000
C  TEST WHETHER TO APPLY THE FULL NEWTON CORRECTION                     BA390100
   41 IS=2                                                              BA390200
      IF(DN - DD)47,47,48                                               BA390300
   47 DD=AMAX1(DN,DSS)                                                  BA390400
      DS=0.25*DN                                                        BA390500
      TINC=1.                                                           BA390600
      IF(DN - DSS)49,58,58                                              BA390700
   49 IS=4                                                              BA390800
      GO TO 80                                                          BA390900
C  CALCULATE THE LENGTH OF THE STEEPEST DESCENT STEP                    BA391000
   48 K=0                                                               BA391100
      DMULT=0.                                                          BA391200
      DO 51 I=1,N                                                       BA391300
      DW=0.                                                             BA391400
      DO 52 J=1,N                                                       BA391500
      K=K + 1                                                           BA391600
      DW=DW + W(K)*X(J)                                                 BA391700
   52 CONTINUE                                                          BA391800
C     THE 1.E+18 TERMS PREVENT MAX FLOAT ERROR ON THE PDP 11 COMPUTER
      IF(ABS(DW).GT.1.E+18) DW=1.E+18
      DMULT = DMULT + DW*DW                                             BA391900
   51 CONTINUE                                                          BA392000
      DMULT=DS/DMULT                                                    BA392100
      IF(ABS(DMULT).GT.1.E+18) DMULT=1.E+18
      DS=DS*DMULT*DMULT                                                 BA392200
C  TEST WHETHER TO USE THE STEEPEST DESCENT DIRECTION                   BA392300
      IF(DS - DD)53,54,54                                               BA392400
C  TEST WHETHER THE INITIAL VALUE OF DD HAS BEEN SET                    BA392500
   54 IF(DD)55,55,56                                                    BA392600
   55 DD=AMAX1(DSS,AMIN1(DM,DS))                                        BA392700
      DS=DS/(DMULT*DMULT)                                               BA392800
      GO TO 41                                                          BA392900
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C  SET THE MULTIPLIER OF THE STEEPEST DESCENT DIRECTION                 BA393000
   56 ANMULT=0.                                                          BA393100
      DMULT=DMULT*SQRT(DD/DS)                                            BA393200
      GO TO 98                                                           BA393300
C  INTERPOLATE BETWEEN THE STEEPEST DESCENT AND THE NEWTON DIRECTIONS   BA393400
   53 SP=SP*DMULT                                                        BA393500
      ANMULT=(DD - DS)/((SP -DS) + SQRT((SP - DD)**2 + (DN - DD)*(DD-DS)BA393600
     1))                                                                 BA393700
      DMULT=DMULT*(1. - ANMULT)                                          BA393800
C  CALCULATE THE CHANGE IN X AND ITS ANGLE WITH THE FIRST DIRECTION     BA393900
   98 DN=0.                                                              BA394000
      SP=0.                                                              BA394100
      DO 57 I=1,N                                                        BA394200
      F(I)=DMULT*X(I) + ANMULT*F(I)                                      BA394300
      DN=DN + F(I)*F(I)                                                  BA394400
      SP=SP + F(I)*W(ND + I)                                             BA394500
   57 CONTINUE                                                           BA394600
      DS=0.25*DN                                                         BA394700
C  TEST WHETHER AN EXTRA STEP IS NEEDED FOR INDEPENDENCE                BA394800
      IF(W(NDC + 1) - DTEST)58,58,59                                     BA394900
   59 IF(SP*SP - DS)60,58,58                                             BA395000
C  TAKE THE EXTRA STEP AND UPDATE THE DIRECTION MATRIX                  BA395100
   50 IS=2                                                               BA395200
   60 DO 61 I=1,N                                                        BA395300
      X(I)=W(NX + I) + DSTEP*W(ND + I)                                   BA395400
      W(NDC + I)=W(NDC + I + 1) + 1.                                     BA395500
   61 CONTINUE                                                           BA395600
      W(ND)=1.                                                           BA395700
      DO 62 I=1,N                                                        BA395800
      K=ND + I                                                           BA395900
      SP=W(K)                                                            BA396000
      DO 63 J=2,N                                                        BA396100
      W(K)=W(K + N)                                                      BA396200
      K=K + N                                                            BA396300
   63 CONTINUE                                                           BA396400
      W(K)=SP                                                            BA396500
   62 CONTINUE                                                           BA396600
      GO TO 1                                                            BA396700
C  EXPRESS THE NEW DIRECTION IN TERMS OF THOSE OF THE DIRECTION MATRIX, BA396800
C  AND UPDATE THE COUNTS IN W(NDC + 1), ETC.                            BA396900
   58 SP=0.                                                              BA397000
      K=ND                                                               BA397100
      DO 64 I=1,N                                                        BA397200
      X(I)=DW                                                            BA397300
      DW=0.                                                              BA397400
      DO 65 J=1,N                                                        BA397500
      K=K + 1                                                            BA397600
      DW= DW + F(J)*W(K)                                                 BA397700
   65 CONTINUE                                                           BA397800
      GO TO (68,66),IS                                                   BA397900
   66 W(NDC + I)=W(NDC + I) + 1.                                         BA398000
      SP=SP + DW*DW                                                      BA398100
      IF(SP - DS)64,64,67                                                BA398200
   67 IS=1                                                               BA398300
      KK=I                                                               BA398400
      X(1)=DW                                                            BA398500
      GO TO 69                                                           BA398600
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   58 X(I)=DW                                                        BA398700
   69 W(NDC + I)=W(NDC + I + 1) + 1.                                 BA398800
   64 CONTINUE                                                       BA398900
      W(ND)=1.                                                       BA399000
C     REORDER THE DIRECTIONS SO THAT KK IS FIRST                     BA399100
      IF(KK - 1)70,70,71                                             BA399200
   71 KS=NDC + KK*N                                                  BA399300
      DO 72 I=1,N                                                    BA399400
      K=KS + I                                                       BA399500
      SP=W(K)                                                        BA399600
      DO 73 J=2,KK                                                   BA399700
      W(K)=W(K - N)                                                  BA399800
      K=K - N                                                        BA399900
   73 CONTINUE                                                       BA300000
      W(K)=SP                                                        BA300100
   72 CONTINUE                                                       BA300200
C     GENERATE THE NEW ORTHOGONAL DIRECTION MATRIX                   BA300300
   70 DO 74 I=1,N                                                    BA300400
      W(NW + I)=0.                                                   BA300500
   74 CONTINUE                                                       BA300600
      SP=X(1)*X(1)                                                   BA300700
      K=ND                                                           BA300800
      DO 75 I=2,N                                                    BA300900
      DS=SQRT(SP*(SP + X(I)*X(I)))                                   BA301000
      DW=SP/DS                                                       BA301100
      DS=X(I)/DS                                                     BA301200
      SP=SP + X(I)*X(I)                                              BA301300
      DO 76 J=1,N                                                    BA301400
      K=K + 1                                                        BA301500
      W(NW + J)=W(NW + J) + X(I - 1)*W(K)                            BA301600
      W(K)=DW*W(K + N) - DS*W(NW + J)                                BA301700
   76 CONTINUE                                                       BA301800
   75 CONTINUE                                                       BA301900
      SP=1./SQRT(DN)                                                 BA302000
      DO 77 I=1,N                                                    BA302100
      K=K + 1                                                        BA302200
      W(K)=SP*F(I)                                                   BA302300
   77 CONTINUE                                                       BA302400
C     CALCULATE THE NEXT VECTOR X, AND PREDICT THE RIGHT HAND SIDES  BA302500
   80 FNP=0.                                                         BA302600
      K=0                                                            BA302700
      DO 78 I=1,N                                                    BA302800
      X(I)=W(NX + I) + F(I)                                          BA302900
      W(NW + I)=W(NF + I)                                            BA303000
      DO 79 J=1,N                                                    BA303100
      K=K + 1                                                        BA303200
      W(NW + I)=W(NW + I) + W(K)*F(J)                                BA303300
   79 CONTINUE                                                       BA303400
      FNP=FNP + W(NW + I)**2                                         BA303500
   78 CONTINUE                                                       BA303600
C     CALL CALFUN USING THE NEW VECTOR OF VARIABLES                  BA303700
      GO TO 1                                                        BA303800
C     UPDATE THE STEP SIZE                                           BA303900
   27 DMULT=0.9*FMIN + 0.1*FNP - FSQ                                 BA304000
      IF(DMULT)82,81,81                                              BA304100
   82 DD=AMAX1(DSS,0.25*DD)                                          BA304200
      TINC=1.                                                        BA304300
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      IF(FSQ - FMIN)83,28,28                                            BA304400
C     TRY THE TEST TO DECIDE WHETHER TO INCREASE THE STEP LENGTH        BA304500
   81 SP=0.                                                             BA304600
      SS=0.                                                             BA304700
      DO 84 I=1,N                                                       BA304800
      SP=SP + ABS(F(I)*(F(I) - W(NW + I)))                              BA304900
      SS=SS + (F(I) - W(NW + I))**2                                     BA305000
   84 CONTINUE                                                          BA305100
      PJ=1. + DMULT/(SP + SQRT(SP*SP + DMULT*SS))                       BA305200
      SP=AMIN1(4.,TINC,PJ)                                              BA305300
      TINC=PJ/SP                                                        BA305400
      DD=AMIN1(DM,SP*DD)                                                BA305500
      GO TO 83                                                          BA305600
C     IF F(X) IMPROVES STORE THE NEW VALUE OF X                         BA305700
   87 IF(FSQ - FMIN)83,50,50                                            BA305800
   83 FMIN=FSQ                                                          BA305900
      DO 88 I=1,N                                                       BA306000
      SP=X(I)                                                           BA306100
      X(I)=W(NX + I)                                                    BA306200
      W(NX + I)=SP                                                      BA306300
      SP=F(I)                                                           BA306400
      F(I)=W(NF + I)                                                    BA306500
      W(NF + I)=SP                                                      BA306600
      W(NW + I)= - W(NW + I)                                            BA306700
   88 CONTINUE                                                          BA306800
      IF(IS - 1)28,28,50                                                BA306900
C     CALCULATE THE CHANGES IN F AND IN X                               BA307000
   28 DO 89 I=1,N                                                       BA307100
      X(I)=X(I) - W(NX + I)                                             BA307200
      F(I)=F(I) - W(NF + I)                                             BA307300
   89 CONTINUE                                                          BA307400
C     UPDATE THE APPROXIMATIONS TO J AND TO AJINV                       BA307500
      K=0                                                               BA307600
      DO 90 I=1,N                                                       BA307700
      W(MW + I)=X(I)                                                    BA307800
      W(NW + I)=F(I)                                                    BA307900
      DO 91 J=1,N                                                       BA308000
      W(MW + I)=W(MW + I) - AJINV(I,J)*F(J)                             BA308100
      K=K + 1                                                           BA308200
      W(NW + I)=W(NW + I) - W(K)*X(J)                                   BA308300
   91 CONTINUE                                                          BA308400
   90 CONTINUE                                                          BA308500
      SP=0.                                                             BA308600
      SS=0.                                                             BA308700
      DO 92 I=1,N                                                       BA308800
      DS=0.                                                             BA308900
      DO 93 J=1,N                                                       BA309000
      DS=DS + AJINV(J,I)*X(J)                                           BA309100
   93 CONTINUE                                                          BA309200
      SP=SP + DS*F(I)                                                   BA309300
      SS=SS + X(I)*X(I)                                                 BA309400
      F(I)=DS                                                           BA309500
   92 CONTINUE                                                          BA309600
      DMULT=1.                                                          BA309700
      IF(ABS(SP) - 0.1*SS)94,95,95                                      BA309800
   94 DMULT=0.8                                                         BA309900
   95 PJ=DMULT/SS                                                       BA310000
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      PA=DMULT/(DMULT*SP + (1. - DMULT)*SS)                           BA310100
      K=0                                                             BA310200
      DO 95 I=1,N                                                     BA310300
      SP=PJ*W(NW + I)                                                 BA310400
      SS=PA*W(NW + I)                                                 BA310500
      DO 97 J=1,N                                                     BA310600
      K=K + 1                                                         BA310700
      W(K)=W(K) + SP*X(J)                                             BA310800
      AJINV(I,J)=AJINV(I,J) + SS*F(J)                                 BA310900
   97 CONTINUE                                                        BA311000
   96 CONTINUE                                                        BA311100
      GO TO 38                                                        BA311200
C-------------------------------------------------------------------  BA311300
  100 WRITE(LPT,99)
   99 FORMAT(2X,17HOVERFLOW FROM GJR  //)                              BA311500
C-------------------------------------------------------------------  BA311600
      GO TO 5
      END                                                             BA311700
@FOR,IS LAGRAN,LAGRAN
      SUBROUTINE LAGRAN(X,XT,YT,NX,NPX,Y,NERR)                        BA319100
      DIMENSION XT(1),YT(1)                                           BA319200
      NERR=0                                                          BA319300
      INTER=1                                                         BA319400
      NP=NPX                                                          BA319500
      IF(NX.LT.NP) NP=NX                                              BA319600
      NS=(NX+159)/26                                                  BA319700
      IH=NP/2                                                         BA319800
      I=1                                                             BA319900
      IF(XT(I)-X)30,20,10                                             BA320000
   10 IH=0                                                            BA320100
   12 NERR=1                                                          BA320200
      GO TO 70                                                        BA320300
   13 NERR=2                                                          BA320400
      GO TO 70                                                        BA320500
   20 INTER=2                                                         BA320600
   22 Y=YT(I)                                                         BA320700
      GO TO 999                                                       BA320800
   30 I=NX                                                            BA320900
      IF(XT(I)-X)13,20,50                                             BA321000
   50 L=IH+1                                                          BA321100
      IS=NS+L                                                         BA321200
      IF(NX-IS)58,58,52                                               BA321300
   52 DO 54 I=IS,NX,NS                                                BA321400
      IF(XT(I)-X)54,20,56                                             BA321500
   54 L=I                                                             BA321600
      GO TO 58                                                        BA321700
   56 L=I-NS                                                          BA321800
   58 DO 60 I=L,NX                                                    BA321900
      IF(XT(I)-X)60,20,70                                             BA322000
   60 CONTINUE                                                        BA322100
   70 K=I-IH                                                          BA322200
      N=K+NP-1                                                        BA322300
      Y=0.0                                                           BA322400
      IF(N-NX)90,90,80                                                BA322500
   80 N=NX                                                            BA322600
      K=NX-NP+1                                                       BA322700
   90 DO 120 J=K,N                                                    BA322800
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      P=1.0                                                         BA322900
      DO 110 I=K,N                                                  BA323000
      IF(I-J)100,110,100                                            BA323100
  100 P=P*(X-XT(I))/(XT(J)-XT(I))                                   BA323200
  110 CONTINUE                                                      BA323300
  120 Y=Y+YT(J)*P                                                   BA323400
  999 RETURN                                                        BA323500
      END                                                           BA323600
@FOR,IS GJR,GJR
      SUBROUTINE GJR(A,NC,NR,N,MC,ICHK,JC,V)                        BA323800
      DOUBLE PRECISION A(NR,NC)
      DIMENSION JC(1),V(2)
C                    -----------------------------------------------BA324000
C                    JC IS THE PERMUTATION VECTOR                   BA324100
C                    KD IS THE OPTION KEY FOR DETERMINANT EVALUATION BA324200
C                    KI IS THE OPTION KEY FOR MATRIX INVERSION      BA324300
C                    L IS THE COLUMN CONTROL FOR AX=B               BA324400
C                    M IS THE COLUMN CONTROL FOR MATRIX INVERSION   BA324500
C                    -----------------------------------------------BA324500
C                    INITIALIZATION                                 BA324700
C                    -----------------------------------------------BA324800
      ICHK=0                                                        BA324900
      IW=V(1)                                                       BA325000
      M=1                                                           BA325100
      S=1.                                                          BA325200
      L=N+(MC-N)*(IW/4)                                             BA325300
      KD=2- MOD(IW/2,2)                                             BA325400
      IF(KD.EQ.1) V(2)=0.                                           BA325500
      KI=2- MOD(IW,2)                                               BA325600
      GO TO ( 10, 30 ),KI                                           BA325700
C                    -----------------------------------------------BA325800
C                    INITIALIZE JC FOR INVERSION                    BA325900
C                    -----------------------------------------------BA326000
   10 DO  20  I=1,N                                                 BA326100
   20 JC(I)=I                                                       BA326200
C                    -----------------------------------------------BA326300
C                    SEARCH FOR PIVOT ROW                           BA326400
C                    -----------------------------------------------BA326500
   30 DO  150  I=1,N                                                BA326500
      GO TO ( 50 , 40 ),KI                                          BA326700
   40 M=I                                                           BA326800
   50 IF (I.EQ.N)  GO TO  100                                       BA326900
      X=-1.                                                         BA327000
      DO  60  J=I,N                                                 BA327100
      IF (X.GT.ABS(A(J,I)))  GO TO   60                             BA327200
      X=ABS(A(J,I))                                                 BA327300
      K=J                                                           BA327400
   60 CONTINUE                                                      BA327500
      IF(K.EQ.I) GO TO  100                                         BA327500
      S=-S                                                          BA327700
      V(1)=-V(1)                                                    BA327800
      GO TO (  70 ,  80 ),KI                                        BA327900
   70 MU=JC(I)                                                      BA328000
      JC(I)=JC(K)                                                   BA328100
      JC(K)=MU                                                      BA328200
C                    -----------------------------------------------BA328300
C                    INTERCHANGE ROW I AND ROW K                    BA328400
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C                         ------------------------------------------------------BA328500
   80  DO   90   J=M,L                                                          BA328600
       X=A(I,J)                                                                 BA328700
       A(I,J)=A(K,J)                                                            BA328800
   90  A(K,J)=X                                                                 BA328900
C                         ------------------------------------------------------BA329000
C                         TEST FOR SINGULARITY                                  BA329100
C                         ------------------------------------------------------BA329200
  100  IF (ABS(A(I,I)).GT.0.)  GO TO  110                                       BA329300
C                         ------------------------------------------------------BA329400
C                         MATRIX IS SINGULAR                                    BA329500
C                         ------------------------------------------------------BA329600
       IF(KD.EQ.1) V(1)=0.                                                      BA329700
       JC(1)=I-1                                                                BA329800
       GO TO 220                                                                BA329900
  110  GO TO ( 120 , 130 ),KD                                                   BA330000
C                         ------------------------------------------------------BA330100
C                         COMPUTE DETERMINANT                                   BA330200
C                         ------------------------------------------------------BA330300
  120  IF(A(I,I).LT.0.) S=-S                                                    BA330400
        V(2)=V(2)+ALOG(ABS(A(I,I)))                                             BA330500
  130  X=A(I,I)                                                                 BA330600
       A(I,I)=1.                                                                BA330700
C                         ------------------------------------------------------BA330800
C                         REDUCTION OF THE I-TH ROW                             BA330900
C                         ------------------------------------------------------BA331000
C                         TEST OVERFLOW SWITCH. IF ON                           BA331100
C                         RETURN NEGATIVE VALUE OF I IN JC(1)                   BA331200
C                         ------------------------------------------------------BA331300
       DO  140  J=M,L                                                           BA331400
       A(I,J)=A(I,J)/X                                                          BA331500
       IF(ABS(A(I,J)).GT.1.E+15) IFL=1                                          BA331600
       IF(IFL.EQ.1) GO TO  230                                                  BA331700
  140  CONTINUE                                                                 BA331800
C                         ------------------------------------------------------BA331900
C                         REDUCTION OF ALL REMAINING ROWS                       BA332000
C                         ------------------------------------------------------BA332100
       DO  160   K=1,N                                                          BA332200
       IF (K.EQ.I)  GO TO  160                                                  BA332300
       X=A(K,I)                                                                 BA332400
       A(K,I)=0.                                                                BA332500
       DO  150   J=M,L                                                          BA332600
       A(K,J)=A(K,J)-X*A(I,J)                                                   BA332700
C                         ------------------------------------------------------BA332800
C                         TEST OVERFLOW SWITCH. IF ON                           BA332900
C                         RETURN NEGATIVE VALUE OF I IN JC(1)                   BA333000
C                         ------------------------------------------------------BA333100
       IF(ABS(A(K,J)).GT.1.E+15) IFL=1                                          BA333200
       IF(IFL.EQ.1) GO TO  230                                                  BA333300
  150  CONTINUE                                                                 BA333400
  160  CONTINUE                                                                 BA333500
C                         ------------------------------------------------------BA333600
C                         AX=B AND DET(A) ARE NOW COMPUTED.                     BA333700
C                         ------------------------------------------------------BA333800
       GO TO ( 170 , 220  ),KI                                                  BA333900
C                         ------------------------------------------------------BA334000
C                         PERMUTATION OF THE COLUMNS FOR MATRIX INVERSION       BA334100
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C     ----------------------------------------------------------------BA334200
  170 DO  210    J=1,N                                                 BA334300
      IF (JC(J).EQ.J)  GO TO  210                                      BA334400
      JJ=J+1                                                           BA334500
      DO  190    I=JJ,N                                                BA334600
      IF (JC(I).EQ.J)  GO TO  190                                      BA334700
  180 CONTINUE                                                         BA334800
  190 JC(I)=JC(J)                                                      BA334900
      DO  200    K=1,N                                                 BA335000
      X=A(K,I)                                                         BA335100
      A(K,I)=A(K,J)                                                    BA335200
  200 A(K,J)=X                                                         BA335300
  210 CONTINUE                                                         BA335400
  220 JC(1)=N                                                          BA335500
      IF(K).EQ.1) V(1)=S                                               BA335600
      RETURN                                                           BA335700
  230 JC(1)=1-I                                                        BA335800
      IF(K).EQ.1) V(1)=S                                               BA335900
      ICHK=1                                                           BA336000
      GO TO 220                                                        BA336100
      END                                                              BA336200
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